Baltic Committee **ICES CM 2001/H:04**

REPORT OF THE

STUDY GROUP ON MULTISPECIES PREDICTIONS IN THE BALTIC

Charlottenlund, Denmark
7–11 May 2001

International Council for the Exploration of the Sea

Conseil International pour l'Exploration de la Mer

Palægade 2–4 DK–1261 Copenhagen K Denmark

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1 INTRODUCTION

1.1 Participation

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1.2 Terms of Reference

According to Annual Science Conference Resolution (2H03) in Brugge last year the Study Group on Multispecies Predictions in the Baltic [SGMPB] (Chair: E. Aro, Finland) will meet in Charlottenlund, Denmark from 7–11 May 2001 to undertake the tasks as specified in (C.Res 1999/2H05) i.e.:

1) explore, in more detail, available and presently formulated medium- to long-term multispecies prediction methodology, including a thorough testing of the 4M software package in this respect;
2) develop, apply and validate different types of multispecies prediction models with sufficient, but not over-emphasised complexity, considering environmental processes affecting prey selection and total food intake, growth, maturation and egg production as well as subsequent recruitment success;
3) evaluate the stability and suitability of biological reference points considering multispecies interactions, environmental processes and their spatial heterogeneity;
4) explore the feasibility of introducing statistically based spatial multispecies frameworks in the Baltic, allowing modelling of migration rates in comparison to observations from tagging experiments.

SGMPB will report by 11 June 2001 for that attention of the Baltic Committee.

The meeting was originally scheduled to take place in November 2000 (C.Res 1999/2H05), but it was not possible to have the meeting at that date and thus it was decided to postpone the meeting to May 2001.

The current activities of the SG will in best case lead ICES into issues of predator-prey relationships in the Baltic, as well as to define multispecies precautionary reference points, which should be considered to have high priority in future management advice in the Baltic Main Basin as well as in the western Baltic.

1.3 Background

In the Baltic Sea, the interacting fish community in the open sea is dominated by three species namely cod, herring, and sprat. The abundance of cod stock in the Main Basin is currently low, herring stocks are decreasing, and the sprat stock is at high level. The effect of cod on prey species (herring and sprat) is now low level. Multispecies interactions are present and they will become important, when predator population recovers. While cod biomass is low, there is the potential for herring and sprat to have an adverse effect on cod recruitment, through consumption of eggs and larvae.

The multispecies interactions in the Baltic are rather clear and strong, Thus it is relative easy to demonstrate how species interactions effect our assessments of the state of the stocks and our perception of the interactions.

Baltic multispecies assessment process started about 20 years ago and presently the following multispecies assessments are available for the Baltic Sea according to ICES sub-divisions (Figure 1.3.1):

- Baltic Main Basin: Years 1974–2000
  - cod in Sub-divisions 25–29+32,
  - sprat in Sub-divisions 25–32,
  - herring in Sub-divisions 25–29+32,
- Western Baltic: Years 1977–1997
  - cod in Sub-divisions 22+24 (only in 1996 and 1997 Sub-division 23 is included),
  - sprat in Sub-divisions 22–24,

- o herring in Sub-divisions 22–24 including Division IIIa.

- Baltic Main Basin: Years 1974–1999, area disaggregated MSVPA:
  - o cod in Sub-divisions 25, 26 and 28
  - o sprat in Sub-divisions 25, 26 and 28
  - o herring in Sub-divisions 25, 26 and 28

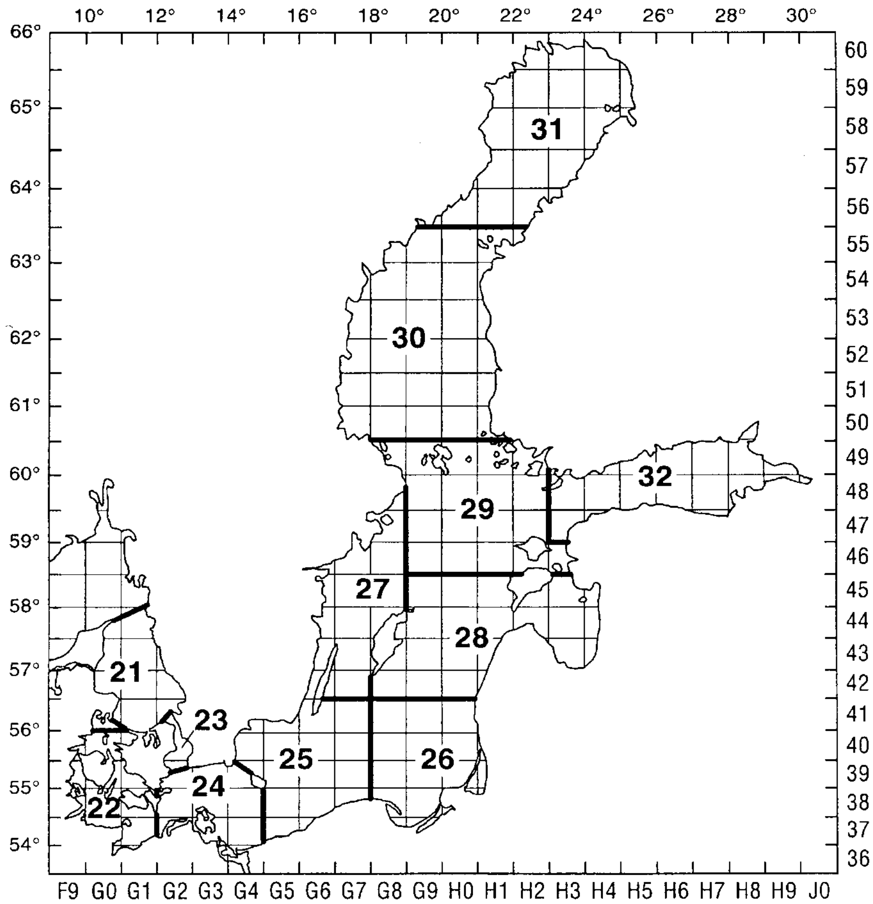


Figure 1.3.1. ICES Sub-divisions in the Baltic.

In the case of Main Baltic herring, the assessment unit is directly comparable to the units used by the Baltic Fisheries Assessment Working Group, although in their 2001 meeting WGBFAS used new stock assessment units for Baltic herring in the Main Basin (ICES 2001). As the sprat population in Sub-division 30 is rather low and in sub-division 31 almost non- existing, the Baltic Main Basin stock estimates are basically also referring to Sub-division 25–32.

Consequently the effect of ignoring the two Sub-divisions should not hamper a direct comparison between single species and multispecies assessment output in the case of cod and sprat.

1.4 Supporting Projects

Under the ICES framework the SGMPB benefits from the activities of Baltic Fisheries Assessment Working Group (WGBFAS). WGBFAS compiles the main input information needed for SGMPB since 1997, which is highly appreciated.

The WGBIFS (Baltic International Trawl Surveys Working Group) reports information on weight at age in the stock for cod based on 1st quarter and 4 quarter bottom trawl surveys and compile the information for VPA tuning files from the surveys.

Data on abundance of herring and sprat as well as data on weight at age in the stock is available from international hydroacoustic surveys, which are conducted “annually” in September/October. Both these data sets can be used to establish a stock specific weight at age database, however, not covering all quarters, which consequently requires modelling of seasonal growth to ensure complete seasonal coverage.

There are activities on modelling growth, sexual maturation and egg production in relation to food consumption, food availability and environmental conditions, especially temperature in the framework of STORE and SAP (Sustainable Fisheries), which are available for SGMPB.

The work of the SGMPB depends upon the results of various European Union funded projects and some of ICES Study Groups and Working Groups. The work and tasks of SGMPB are partly covered within the EU Concerted Action “Sustainable Fisheries Project” (SAP) and EU research project on stock recruitment of cod and sprat in the Baltic (STORE).

Within European Union, SGMPB will benefit from results of number of other, either completed or ongoing projects and study projects. Such projects are CORE (Cod Recruitment, completed at the end of 1997), ISDBITS (International Standardization of Baltic Bottom Trawl Surveys, completed in March 2001), BALTDAT (Baltic International Hydroacoustic Surveys, completed in March 2001), BITS (Baltic International Trawl Survey Database, completed in April 2001) and IBSSP (International Baltic Sea Sampling Project I-II, will be completed in July 2001). All these are linked to this SG and the SG is fortunate to have the possibility to exploit their findings and results.

At the beginning of year 2002 the European Union Regulation N° 1543/2000 will establish a new framework for the collection and management of data needed to evaluate the situation of the fishery resources and the fisheries sector in general. In EU countries national programmes are defined for the collection and management of fisheries fish stock data. The programmes will cover the information strictly necessary for the scientific evaluations and moreover to define an extended Community programme which includes, in addition to the information of the minimum programme, information likely to improve in a decisive way the scientific evaluations. The assessment of Baltic fish stocks will be very much dependent on these sampling schemes and programmes.

1.5 Overview of Baltic Sea Multispecies Modelling

There is certainly a need for specific work to keep the capability of running updated multispecies models for the Baltic within the ICES community and to ensure further progress in multispecies modelling in the Baltic. Updated multispecies model results are used by WGBFAS annually and the new predation mortalities are used for Baltic herring and sprat assessments. These single species assessments for cod, herring and sprat are the basis for management advice for IBSFC.

The maintenance of the data-base, data-base revision and updates, which incorporate basic multispecies products, need input from the Danish Fisheries Research Institute. Backwards extension of the MSVPA to periods before 1977 with the aim to enlarge the time series on stock developments especially for stock-recruitment modelling purposes is in principal possible and in fact this has been completed now to the year 1974. The Eastern Baltic MSVPA now covers years 1974–2000 and spatially disaggregated model years 1974–1999.

To update databases backwards to 1960s and early 1970s may be possible, but there might be severe problems compiling quarterly data by sub-divisions. In this process the most obvious limiting factor will be the poor quality quarterly catch at age and weight at age data, especially before 1974 and this raises the question is this extension worth of doing? This however should be explored in co-operation with WGBFAS.

There are also considerable amounts of stomach content data for the 1960s and 1970s and this information would be very useful for estimation of consumption rates and understand cod cannibalism. We can foresee, that no new stomach data will be sampled in high numbers in the future.

From inspection of the original stomach content data, cannibalism appears to be related both to the prey sizes and spatial overlap. However, cannibalism is most likely also related to shifts in the distribution of predator and prey in response to changes in hydrographical conditions, resulting in pronounced changes in the spatial overlap of predator and prey. This part of exploratory work is still ongoing.

Our predictive models are sensitive to structural uncertainty. For example, with inclusion of weight at age and maturity at age being dependent on the food supply, the projected medium-term yield at various combinations of fishing effort directed to both cod and clupeids stocks change considerably in comparison to ordinary standard multispecies predictions.

Spatially disaggregated MSVPA runs have been updated for the Central Baltic. The results support the theory that passive transport of youngest life stages of cod and migration by juveniles into/out of their nursery areas as well as spawning migrations of adults between different Sub-divisions are likely to occur. The intensity between years varies and there is not for time being clear estimates throughout the years and nor spawning seasons about the extent of these movements. Similarly for herring and sprat, the MSVPA output does not match the distribution pattern obtained from research surveys, indicating conflicting results caused probably by migration and movements. However, the integrated results over the whole area coincide with the results of the assessed stock.

The 4M programme, which contain MSVPA has been already tested and some intersessional work has been done by the Danish Institute for Fisheries Research. The MSVPA related routines, including the new tuning module, have been run in general without problems.

Thus, the present programme package enables for example WGBFAS to run MSVPA’s on a regular basis. An updated user manual giving specification and documentation of the 4M package has been compiled and is available on request (Vinther *et al.* 2001).

For development, application and validation of different types of multispecies prediction models, one of the key elements seems to be environmental variability. For example Baltic cod recruitment, feeding, growth and maturation processes are very much influenced by the heterogeneity of the physical environment.

In the Baltic Sea environmental variability is strongly linked to the meteorological-, hydrological-, and hydrographical processes and their interaction. As a result, the impact or change of one factor may well be correlated with that of others. How they interact has not been considered yet and the relationships between various processes and hydrodynamics need to be explored. This may apply all three species in MSVPA model.

Baltic Sea oceanographic data usually consist of indices that reflect and integrate multiple processes. They often contain indices that reflect the influence of remote forcing over a broad geographic area, direct measurements that reflect measured variables on a local scale or predicted elements generated from detailed models of an specific area. The use of these indices instead of local observations is often the result of limited monitoring resources or limited knowledge at the local scale. How to use these values or indices properly, should be explored.

Reference points, stated in terms of fishing mortality rates or biomass and management plans are key concepts in implementing a precautionary approach. It has been agreed, but not fully understood, that reference points should be regarded as signposts giving information of the status of the stock. It has been possible to develop rather clear concepts and a "quantitative framework" with reference points and management models for single stock sustainability and precautionary. For multispecies situations the sustainability concept seems to be very different and difficult. Although Baltic Sea is considered to be a simple ecosystem, there is still little clarity on the conceptual level given the complexity and natural variability of that environment. Reference points are far away from being defined given the limited understanding of the processes in the environment, of the effects of human interaction and of what comprises a perturbation of the environment, which is unsustainable or perhaps irreversible.

Medium- to long-term projection methodology is a problem for single species approach and for multispecies as well. However, the present version of 4M-programme package is able to handle a variety of stock recruitment relationships with and without stochasticity, as well as stochastic recruitment derived from normal or lognormal distributions. However, the programme is presently not able to incorporate environmental processes into stock recruitment relationships. The inclusion of environmental variability in predictions is worthwhile when assessing the impact of various management and fishing strategies on the stock development under different environmental conditions.

2 STATUS OF THE DATABASES AND MSVPA SET-UP

2.1 Stock Units

The stock units utilized in the present MSVPA for the Central Baltic are: i) cod in Sub-divisions 25–29+32, ii) sprat in Sub-divisions 25–32, and iii) herring in Sub-divisions 25–29, 32 (Gulf of Riga included). In the case of herring, the assessment unit is directly comparable to the one used by the Baltic Fisheries Assessment Working Group for the

Central Baltic (ICES 2001/ACFM: 18). As the sprat population in Sub-division 30 and 31 is rather low (landings are less than 5000 t in most recent years), the stock estimate is basically also referring to Sub-division 25–29+32. To estimate the predation mortality on these stocks, the cod assessment unit was adjusted accordingly, thus not considering part of the stock in Sub-division 30 and 31. Landings reported in these Sub-divisions are in general less than 1% and in maximum 3.5% of the total catch from the Central Baltic. Consequently the effect of ignoring the two Sub-divisions should not hamper a direct comparison between single species and multispecies assessment output. For sprat, the multi- and single species assessment units are not directly comparable, as in the latter the sprat stock in entire Baltic is treated as a single stock unit.

2.2 Catch at Age

2.2.1 Period 1974–1992

During the meetings of the Study Group on Multispecies Model Implementation in the Baltic (ICES 1997/J:2 and ICES 1999/H:5) revised and corrected quarterly catch at age and weight at age in the catch data per Sub-division were compiled for cod, sprat and herring in the Central Baltic. This enables multispecies assessments to be carried out for stock units defined as appropriate, i.e., presently those used by the Baltic Fisheries Assessment Working Group. As preparation for the present Study Group meeting the catch at age database was updated to include the period 1974–1976 and also further corrections for the period 1977–1992 were made. Nevertheless, the revision of the database needs allocation of additional effort, especially for the newly included early years for which still data exist in various national laboratories and with respect to potential corrections for age-reading discrepancies in cod. Furthermore, no discard estimates were not included in the data. A necessary step after incorporation of all available information and re-computation of quarterly data per Sub-division according to the agreed substitution scheme (ICES 1997/J:2), is a further validation of the assessment data by comparison of SOP-values to actual reported landings. Based on this validation, a final revision of the database has to be conducted, before handing over the data-base to the Baltic Fisheries Assessment Working Group.

2.2.2 Period 1993–2000

Data for all three species were provided in the needed form by the Baltic Fisheries Assessment Working Group in most recent years, for minor deviations between the single- and multispecies database see ICES (1999/H:5). As in previous years, the data for the most recent year of the assessment year was implemented into the multispecies data-base as provided by the Baltic Fisheries Assessment Working Group (ICES 2000/ACFM:18). Herring catches in 1999 were used in the updated form as reported by ICES (2000/ACFM:18).

2.3 Mean Weight at Age

2.3.1 Mean weight at age in the catch

Mean weight at age in the catch for the period 1977–1992 were used as compiled by ICES (1997/J:2), while for the period 1993–2000 data supplied by the Baltic Fisheries Assessment WG was utilized. Due to several cases of missing information, weight at age in 1974–1976 were assumed to be equal to 1977 for all three species.

2.3.2 Mean weight at age in the stock

During its meeting in 1998 the Baltic Fisheries Assessment Working Group (ICES 1998/ACFM:16) has started a compilation of available weight at age in the stock data for cod, based on 1st quarter bottom trawl surveys. A comparison of weight at age in the catch from the compiled database and these stock specific data revealed significant differences for juvenile cod (age-groups 0–2). Thus for the Central Baltic, average weight at age in the stock have been established for the period 1990–97 by using bottom trawl survey data from the 1st quarter and interpolating to other quarters, while before old MSVPA weight at age in the stock (set constant over years) were used (ICES 1999/H:5). For herring and sprat a similar test did not reveal the necessity to introduce stock specific weight at age, as available data from hydroacoustic surveys were in general similar to corresponding catch specific data.

2.4 Maturity Ogives

For the cod, Sub-division based data were calculated for 5 years periods, i.e., 1980–1984, 1985–1989 and 1990–1994 by Tomkiewicz *et al.* (1997). For the period 1995–1997, 1998 and 1999 yearly maturity ogives on Sub-division basis are available (ICES 1998/ACFM:16, ICES 1999/ACFM:15, ICES 2000/ACFM:14). Maturity data averaged over Sub-divisions for the entire Central Baltic (as applied in the combined MSVPA-runs) were compiled by the Baltic Fisheries

Assessment Working Group for the same time periods. For the year 2000 a mean maturity at age for the period 1997–1999 was applied, corresponding to the procedure adopted by the assessment WG (ICES 2001/ACFM:18). For the sprat and herring stocks no changes to the maturity ogives were applied. The data sets are described in ICES (1997/J:2).

2.5 Stomach Content Information

The stomach content database contains the major part of the information available for the period 1977–1993. Stomach sampling activity has been very limited in most recent years, and this data material has not been incorporated into the database so far. Likewise available information for the period 1974–1976 has not been included in the database. Backwards extension of the MSVPA to periods before 1974 with the aim to enlarge the time series on stock developments especially for recruitment modelling purposes is in principal possible, as considerable amounts of stomach content data exist for the 1960s and 1970s. However, the limiting factor of such an extension will probably be the insufficient reliability of quarterly catch at age and weight at age data available.

2.6 Food Consumption Rates

Based on the cod stomach content data-base updated by ICES (1997/J:2), quarterly consumption rates were revised based on re-calculated ambient temperatures, according to the procedure outlined by ICES (1999/H:5).The consumption model in use, corresponds to the one applied in the North Sea (ICES 1997/Assess:16), based on a general model of gastric evacuation, considering actual environmental temperatures and predator weights as additional variables. As stomach content data are available for most of the quarters and years covered by the present MSVPA, in general also for different areas of the Central Baltic, consumption rates were computed for every predator age group, quarter, year and Sub-division. Missing quarters/years, i.e., also the years 1974–1977 and 1994–200 were substituted according to ICES (1999/H:5). Average ambient temperatures in a given Sub-division were derived by ICES (1999/H:5) from the ICES hydrographic data-base, by calculating a weighted average taking into account the distribution pattern of cod in different depths strata obtained from the BITS-data-base for the 1st quarter. During the present SG meeting these ambient temperatures were updated and revised as computation errors were detected in the calculation performed by ICES (1999/H:5). The revised ambient temperatures for 0 and 1-group, 2-group and 3+ group cod are presented in Table 2.6.1. To derive consumption rates for the central Baltic, average values were calculated by weighting with the relative distribution of cod utilized also to determine average stomach contents. The new and the old estimates are presented as averages over the periods 1977–1997 (to allow comparison) in Figure 2.6.1, showing that the new estimates are consistently higher. Thus, the discrepancy between applied consumption estimates and those derived for the North Sea and for Baltic cod by a bioenergetics model (ICES 1999/H:5) has been reduced. Nevertheless, food conversion efficiencies are still relatively high, however being in a realistic range considering comparatively low stomach contents, low ambient oxygen concentration, temperatures and salinities as well as relatively high growth rates in Baltic cod. Despite the difference in the absolute magnitude, the time trends in old and revised consumption rates are rather similar (Figure 6.2.2).

2.7 Possible Data Improvements

The revision of the catch at age and weight at age database according to quarter and Sub-division for the period 1974–92, handled by the Institute of Marine Sciences in Kiel, needs allocation of additional effort, especially with respect to the earliest years of the time series. A further necessary step after incorporation of all available information and re-computation of quarterly data per Sub-division according to the agreed substitution scheme, is a validation of the assessment data, e.g., by comparison of SOP-values to actual reported landings in smallest time and area units available. This procedure (see ICES 1999/H:5 and ICES 1997/J:2) allows to identify major discrepancies between the present single- and the new multispecies data-base, caused by either computation errors or substitution of missing information with unsuitable or erroneous data. Based on this validation, a final revision of the data-base has to be conducted, before handing over the end product to the Baltic Fisheries Assessment Working Group, which should take care of an annual update, as already started in 1997. This will, however, not solve the problems in setting up reliable catch at age and weight at age in the catch data for the Western Baltic stocks, which has not been has not been proceeded beyond status described in ICES (1997/J:2).

During its meeting in 1998 the Baltic Fisheries Assessment Working Group (ICES 1998/ACFM:16) has started a compilation of available weight at age in the stock data for cod, based on 1st quarter bottom trawl surveys. Similarly, data on weight at age in the stock for herring and sprat are available from international hydroacoustic surveys conducted annually in September/October. Both data sets can be used to establish a stock specific weight at age data-base, however, not covering all quarters, which consequently requires modelling of seasonal growth to ensure complete seasonal coverage.

The stomach content database contains the major part of the information available for the covered time period 1977–1993, and as stomach-sampling activity has been very limited in most recent years, only limited effort for an update of the database is required for most recent years. However, inclusion of earlier data covering, e.g., 1974–1976, may be worthwhile as a as considerable amounts of stomach content data exist for the 1960s and 1970s. Further backwards extension of the MSVPA to periods before 1974 with the aim to enlarge the time series on stock developments especially for recruitment modelling purposes is in principal possible. However, the limiting factor of such an extension will be the insufficient reliability of quarterly catch at age and weight at age data available, especially before 1974. Maintenance of the database needs limited input from the Danish Fisheries Research Institute presently holding the database. Apart of these potential improvements, a high priority should be allocated to solve the age-reading inconsistencies allowing to set-up a procedure correcting available age-based data sets. To ensure the allocation of necessary effort for these different tasks, the Group recommends to set-up of an internationally coordinated project dealing with database revision and validation, as well as developing procedures for their routine update and outlining maintenance strategies.

Table 2.6.1 Revised ambient temperatures of cod age-groups 0 and 1 in Sub-divisions (SD) 25, 26 and 28 according to quarter (Q).

Year	SD 25				SD 26				SD 28			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1974	5.90	5.78	7.50	7.82	3.88	4.54	4.11	6.30	3.93	4.51	5.05	5.51
1975	6.89	7.00	6.94	8.06	4.53	4.71	5.95	6.72	4.28	5.22	5.37	5.94
1976	5.27	4.21	4.88	7.61	3.67	3.15	5.58	5.68	3.65	3.82	4.47	4.93
1977	6.29	5.42	5.78	6.88	3.80	3.81	3.83	5.85	3.95	4.30	5.82	5.76
1978	6.96	5.99	6.92	8.63	3.69	3.50	4.73	6.40	3.95	3.95	4.43	5.17
1979	7.32	3.53	5.42	6.77	3.71	2.53	3.92	6.31	4.05	3.66	3.62	5.11
1980	6.82	4.15	3.83	5.42	2.17	2.99	3.09	4.59	3.47	3.62	3.73	5.15
1981	6.27	5.88	4.97	7.07	2.89	3.11	2.91	6.38	3.65	3.53	3.98	4.69
1982	5.17	4.81	5.24	7.42	2.38	3.07	4.71	5.03	2.76	3.56	3.62	6.14
1983	6.80	6.21	6.56	7.31	3.84	3.97	4.06	7.77	4.02	3.68	4.65	5.09
1984	5.73	4.75	6.30	7.50	4.00	3.55	4.49	5.39	4.34	3.88	4.11	4.52
1985	6.60	4.34	4.66	5.22	3.72	3.26	4.49	4.27	4.37	3.82	3.70	3.92
1986	4.67	3.30	5.32	6.95	3.55	2.30	3.09	3.47	3.90	3.00	3.23	3.49
1987	4.70	4.22	4.68	5.95	3.14	2.76	2.75	3.69	3.01	2.62	2.84	3.47
1988	5.37	4.95	5.03	7.25	3.39	3.36	3.07	5.57	3.69	3.69	3.67	3.76
1989	6.48	6.37	6.31	8.16	3.70	4.29	3.98	6.23	3.72	3.84	3.87	4.15
1990	5.66	6.31	6.79	8.12	4.58	5.81	5.20	7.58	4.09	4.58	4.55	6.76
1991	5.69	4.23	5.63	8.28	5.24	5.10	7.03	6.18	4.90	4.57	4.56	4.57
1992	5.22	5.43	6.93	8.20	4.14	4.83	5.54	8.45	4.53	4.48	4.61	5.21
1993	4.50	4.23	5.35	6.95	3.40	4.31	7.64	6.87	3.89	3.76	3.86	4.73
1994	4.29	3.81	4.39	5.41	2.91	2.75	7.23	6.68	4.43	4.34	4.16	4.61
1995	4.61	4.93	6.03	8.00	3.26	4.44	4.62	6.26	3.03	2.66	3.22	5.74
1996	2.15	2.51	4.17	7.68	1.43	2.92	5.23	7.47	1.23	2.72	3.37	3.74
1997	5.55	4.82	5.58	9.16	3.69	3.81	4.17	6.03	2.72	3.61	3.74	4.28
1998	6.19	5.48	6.22	7.67	4.12	4.10	4.47	5.36	3.92	3.65	3.72	4.66
1999	5.45	5.29	6.22	7.67	4.12	4.11	5.33	5.36	3.30	3.67	3.54	4.19
2000	5.09	5.02	5.57	6.34	4.12	4.54	5.33	5.14	3.30	3.67	3.54	4.19

Table 2.6.1 continued. Revised ambient temperatures of cod age-group 2 in Sub-divisions (SD) 25, 26 and 28 according to quarter (Q).

Year	SD 25				SD 26				SD 28			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1974	5.59	5.80	5.43	7.78	4.26	4.69	5.87	6.33	3.80	4.39	4.86	5.35
1975	6.55	6.71	7.59	8.09	4.83	4.93	5.62	6.56	4.18	5.09	5.20	5.93
1976	4.95	4.08	6.95	7.76	4.02	3.40	3.92	5.69	3.51	3.66	4.25	4.96
1977	5.90	5.22	4.94	7.12	4.22	4.05	4.80	5.72	3.84	4.11	5.57	5.62
1978	6.60	5.63	6.03	8.52	4.06	3.74	4.10	6.30	3.79	3.77	4.26	4.96
1979	6.66	3.26	6.63	6.75	4.02	2.91	3.37	5.86	3.92	3.41	3.39	4.72
1980	6.45	4.01	5.24	5.75	2.62	3.18	3.03	4.39	3.33	3.42	3.52	4.81
1981	5.59	5.53	3.93	7.05	3.35	3.45	4.81	6.10	3.51	3.38	3.81	4.46
1982	4.99	4.71	5.27	7.46	2.70	3.31	4.22	5.03	2.87	3.43	3.43	5.36
1983	6.36	5.87	5.25	7.38	4.05	4.09	4.40	7.26	3.98	3.51	4.54	5.38
1984	5.31	4.68	6.38	7.47	4.16	3.72	4.48	5.33	4.23	3.77	4.07	4.65
1985	5.81	3.85	6.35	5.27	4.07	3.54	3.31	4.24	4.35	3.78	3.55	3.80
1986	4.68	3.36	4.47	6.93	3.56	2.46	2.83	3.58	3.90	3.16	3.35	3.63
1987	4.19	3.75	5.32	5.69	3.54	3.12	3.25	3.70	3.23	2.92	3.06	3.43
1988	5.22	4.91	4.50	7.31	3.55	3.48	4.14	5.33	3.51	3.51	3.78	4.28
1989	6.16	6.07	5.14	8.07	3.87	4.45	5.02	5.85	3.81	3.85	3.88	4.13
1990	5.84	6.34	6.14	8.05	4.63	5.82	7.11	7.62	4.15	4.67	4.61	6.44
1991	5.86	4.35	6.94	8.11	5.23	5.03	5.33	5.93	4.92	4.73	4.82	4.80
1992	5.56	5.66	5.85	7.91	4.98	5.58	8.03	8.88	4.57	4.51	4.62	5.17
1993	4.56	4.28	6.76	6.64	2.92	3.40	5.18	5.18	3.97	3.86	3.96	4.78
1994	4.24	3.81	5.19	5.45	3.61	3.30	4.35	5.93	4.34	4.21	4.03	4.48
1995	4.87	5.08	4.42	7.74	3.43	4.36	5.08	5.98	3.59	3.56	3.71	5.64
1996	2.48	2.76	5.88	7.85	2.14	3.67	4.68	7.68	3.07	3.31	3.67	3.85
1997	5.66	4.93	4.37	9.20	4.36	4.30	4.84	6.19	3.49	4.00	4.10	4.40
1998	6.42	5.81	5.65	7.68	4.90	4.75	5.61	5.75	4.53	4.45	4.41	4.86
1999	5.59	5.56	6.63	7.68	4.90	4.77	5.61	5.75	4.32	4.50	4.42	4.70
2000	5.37	5.80	6.63	6.67	4.90	4.77	5.05	5.62	4.09	4.28	4.42	4.70

Table 2.6.1 continued. Revised ambient temperatures of cod age-groups 3+ in Sub-divisions (SD) 25, 26 and 28 according to quarter (Q).

Year	SD 25				SD 26				SD 28			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1974	5.28	5.82	7.67	7.74	4.64	4.84	5.80	5.69	3.67	4.27	4.67	5.19
1975	6.21	6.43	6.96	8.12	5.13	5.15	5.66	6.35	4.09	4.96	5.03	5.92
1976	4.63	3.95	5.01	7.90	4.37	3.66	4.00	6.39	3.36	3.49	4.03	5.00
1977	5.51	5.03	6.28	7.36	4.64	4.29	4.88	5.71	3.74	3.93	5.32	5.48
1978	6.23	5.26	6.34	8.41	4.44	3.98	4.28	5.58	3.63	3.60	4.09	4.74
1979	6.00	2.99	5.06	6.72	4.33	3.29	3.65	6.19	3.80	3.16	3.16	4.34
1980	6.08	3.87	4.02	6.08	3.08	3.37	3.16	5.41	3.18	3.22	3.32	4.47
1981	4.91	5.17	5.57	7.02	3.82	3.80	4.92	4.20	3.36	3.22	3.64	4.23
1982	4.82	4.61	5.25	7.50	3.03	3.55	4.38	5.82	2.97	3.30	3.25	4.57
1983	5.92	5.52	6.20	7.45	4.26	4.21	4.32	5.04	3.95	3.34	4.44	5.67
1984	4.89	4.61	6.40	7.44	4.33	3.88	4.48	6.75	4.12	3.66	4.02	4.77
1985	5.01	3.36	4.29	5.33	4.42	3.81	3.54	5.27	4.32	3.73	3.40	3.69
1986	4.69	3.42	5.31	6.92	3.58	2.62	2.92	4.21	3.91	3.32	3.47	3.77
1987	3.68	3.28	4.33	5.44	3.95	3.48	3.42	3.70	3.45	3.21	3.28	3.39
1988	5.07	4.87	5.25	7.37	3.71	3.60	4.29	3.71	3.32	3.33	3.89	4.81
1989	5.84	5.77	5.97	7.98	4.04	4.61	4.84	5.10	3.89	3.87	3.89	4.11
1990	6.01	6.37	7.09	7.97	4.68	5.83	7.19	5.47	4.20	4.75	4.68	6.11
1991	6.03	4.47	6.07	7.95	5.22	4.97	5.13	7.66	4.94	4.89	5.08	5.04
1992	5.90	5.88	6.59	7.61	5.82	6.34	8.42	5.69	4.60	4.54	4.63	5.12
1993	4.61	4.33	5.03	6.33	2.45	2.49	3.13	9.32	4.05	3.95	4.06	4.83
1994	4.19	3.82	4.46	5.49	4.30	3.86	4.07	3.49	4.25	4.09	3.90	4.35
1995	5.13	5.22	5.72	7.48	3.60	4.27	4.93	5.18	4.15	4.46	4.21	5.54
1996	2.80	3.02	4.57	8.02	2.86	4.41	5.20	5.71	4.92	3.90	3.96	3.97
1997	5.78	5.04	5.71	9.24	5.02	4.80	5.22	7.88	4.25	4.40	4.47	4.52
1998	6.64	6.13	7.04	7.69	5.68	5.41	5.90	6.36	5.14	5.25	5.09	5.05
1999	5.74	5.84	7.04	7.69	5.68	5.43	5.90	6.14	5.33	5.33	5.29	5.20
2000	5.65	5.83	6.73	7.00	5.68	5.43	5.80	6.14	4.88	4.89	5.29	5.20

Figure 2.6.1 Quarterly consumption of cod (averages over years 1977–1997) with corresponding standard error estimated by ICES (1999/H:5) and revised in combined Sub-divisions 25, 26 and 28.

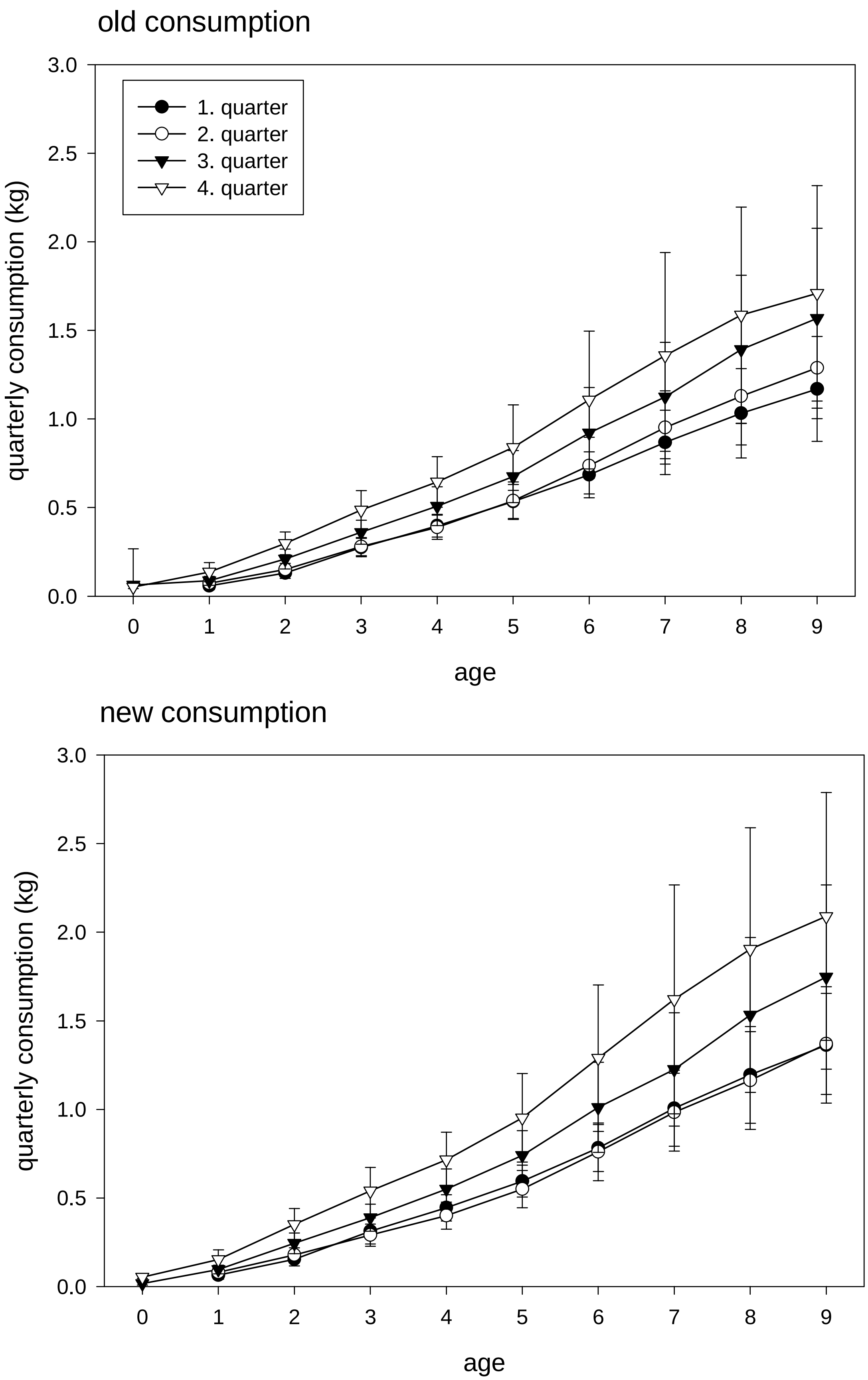
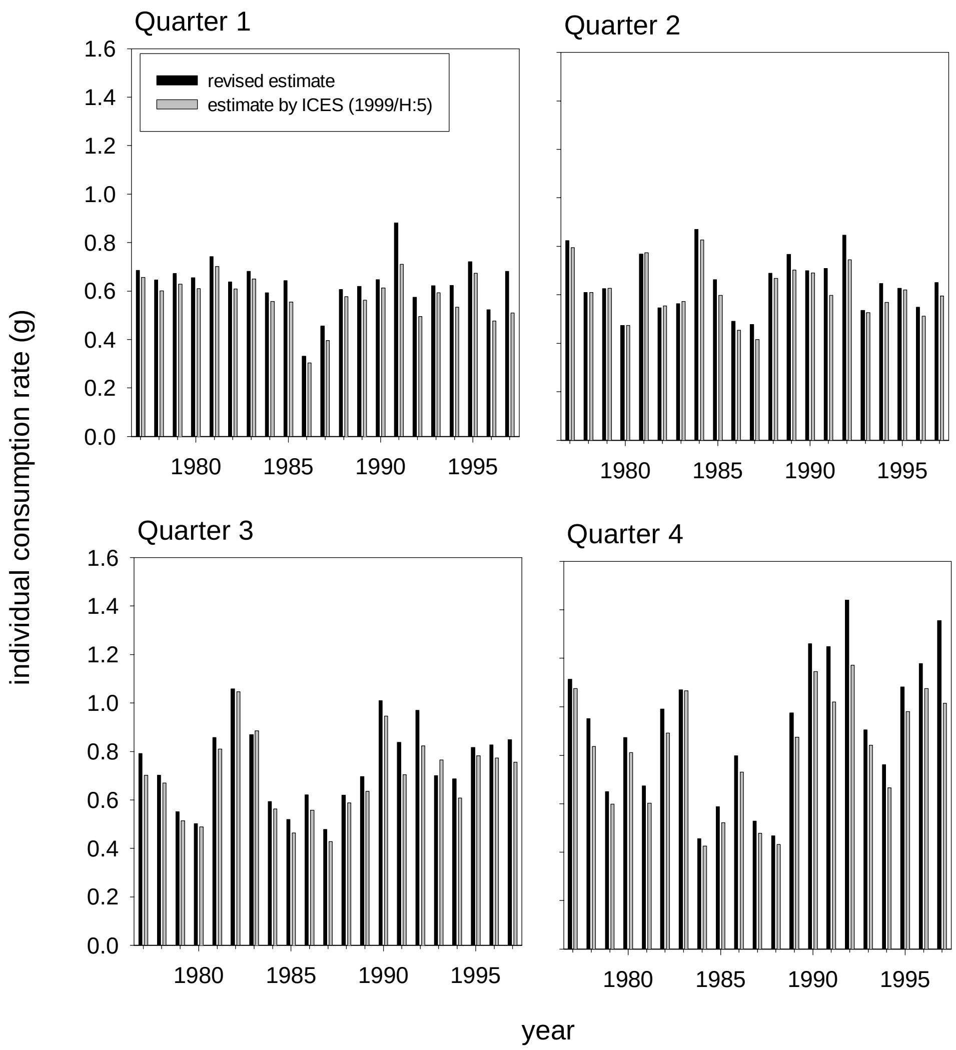


Figure 2.6.2 Time series of quarterly consumption rates estimated by ICES (1999/H:5) and revised (averages over ages).



3 REVIEW OF METHODOLOGY AND PROGRAMS AVAILABLE FOR PERFORMING MULTISPECIES STOCK PREDICTIONS

Because the Study Group had only the 4M program available for projections, no comparisons were made to others. Also, the limited number of participants meant that only a few options using 4M were carried out.

3.1 Multispecies Forecast Models Considering the Dependence of Weight at Age and Maturity at Age on Food Availability

Extending the MSVPA to account for changes in food intake and growth

Food intake and growth is assumed to be constant in the MSVPA and changes in biomass of prey will therefore not affect the growth of their predators. A first step to include bottom up effects in 4M includes growth of VPA predators as a function of the amount of available food. Gislason (1999) has defined and implemented a spreadsheet version of the MSVPA and MSFOR programs for the Central Baltic stocks. The concepts defined in Gislason (1999) have been implemented in 4M with a few modifications due to use of quarterly data instead of annual data.

Weight at age is defined as the weight at age in the proceeding year plus a growth term. Growth depends on average growth observed and the amount of available food in the current period relative to the average amount of available food:

$$W(a,y) = W(a-1,y-1) + \frac{AVAIL\,(a-1,y-1) * \overline{Growth}\,(a-1)}{\overline{AVAIL}\,(a-1)}$$

Where W is the estimated weight in the sea, AVAIL is the amount of available food for the predator and Growth is the average growth observed.

The food intake is defined as a bioenergetics model taking standard metabolism, somatic growth and spawning into account:

$$\left[R(a) = \max\left(b * W(a)^{C} + \frac{W(a+1) - W(a)}{CE(a)} + \frac{PM(a) * W(a) * SPAWN(a)}{SCE(a)}, 0 \right) \right]$$

where

R(a)	food intake
CE(a)	food conversion efficiency, somatic growth
PM(a)	proportion mature
SPAWN(a)	factor of initial body weight lost due to spawning
SCE(a)	food conversion efficiency for spawning products

Estimated weight, food intake and available food are mutual dependent and are estimated by iteration until convergence of the values of estimated weight.

The biomass of other food or total biomass is assumed to be constant in the MSVPA, which seems inconsistent to the assumption of food intake as a function of available food. Average biomass of other food is therefore assumed to be defined by:

$$\overline{B}\,(p,y) = e^{K(p)*L(p)*consumption}$$

where:

B(p,y)	average biomass of other food, p, in year y
K(p)	constant expressing the log of the biomass of other food when predation is zero
L(p)	constant expressing the amount of change in biomass of other food per unit of consumption

The “other food” component can be divided into “other prey” species or taxonomic groups and the parameters K and L must then be given separately for each “other prey” species. For the Baltic Sea area, other prey species might be *Saduria entemon*, mysis and “other, other food items”.

The concept mentioned above might even be used to model variable (density dependent) mean weight at age of herring and sprat. The two species will then act as predators on a number of preys groups, which mean biomass declines as a function of amount eaten leading to variable mean weight.

The extensions to MSVPA work in both the VPA and the prediction mode.

Two approaches could be considered for modelling the maturity at age. One is to write an equation that is an analog to the weight at age one above. The other is to assume that the weight at age is an integral of diet throughout the age of the fish and model maturity as a function of the weight. In practice these two approaches should behave similarly.

The age at maturity could be modelled in an analogous fashion to the weight at age:

$$Mat(a,y) = Mat(a-1,y-1) + b * \frac{AVAIL(a-1,y-1) * \overline{DelMat}(a-1)}{\overline{AVAIL}(a-1)}$$

where DelMat is the analog of growth rate and is the average over a period of time of the change in maturity from one age to the next. This would move the ogive’s position but still have 100% maturity at some age. b is a scaling parameter.

Another approach would be to mediate the maturity at age by the weight at age, which already has the effects of prey availability incorporated. Gislason (1999) used this type of formulation based on a logarithmic regression of proportion mature and weight at age. Similarly, one could reduce the fecundity, instead of the maturity as a function of ration. That is a fully mature fish that was below weight would produce fewer than average recruits. A lower weight limit could be imposed that at which reproduction ceases. As well as reduced reproduction, survivorship could be made dependent upon the weight at age. The problem with these models is because the weight at age is an accumulation of affects over the life of the fish to much emphasis may be given to previous history instead of things within the last few months.

More complex models could be formulated which differential weights are given to recent versus long term affects of availability and hence ration, but there is always the problem of defining parameters for them.

3.2 Multispecies Forecast Models Considering the Dependence of Species Interactions on Environmental Processes

Section 5 of this report; summarize the available evidence for environmental affects on cod and sprat in the Baltic Sea. In this section we consider how can these be incorporated into forecasts. The influences of environmental process can be categorised into three groups depending on how well known the effect is:

- well determined theoretically and empirically
- poorly determined but still enough data to make a good guess
- suspected effects but no appropriate data.

For those interactions for which there are sufficient data to determine parametric relationships (see Table 5.2.1 in Section 5) the job is fairly straight forward and their inclusion is only a matter of a few lines of computer code. This parametric approach is in essence simplifying the biology into algorithms (models) for projection. The goodness of fit information or the residuals from the fit can be used in risk analysis and precautionary analysis, usually in some sort of a bootstrapping process.

Stochastic forecasts should carefully consider the residuals in the various process models. Their shape may be poorly approximated by a normal distribution. Furthermore, rare events may have where either the tail of normal is too probable or not probable enough may have profound effects on a forecast. Also, the residuals may not be independent and the influence of 3 consecutive years of poor environment on recruitment could be different from 3 scattered over a decade. Thus, the common practice of performing stochastic forecasts using only the mean and standard deviation of a parameter may give unwarranted confidence in the probable states in a stock. This in turn would affect risk analysis or precautionary considerations. It is recommended to either bootstrap residuals or carefully describe their distribution.

Insights from meta-analysis of residuals from other stocks may give insights, which would help to anticipate events that have not been seen in the observations for the system under consideration.

Environmental factors influence many (if not all) aspects of ecosystem function. For example, Plikshs *et al* 1993 and Sparholt, 1996 incorporated a spawning volume term into the stock recruit relationship for cod. Temperature will influence almost all stages of fish biology from larval development to adult survivorship (see text table in section 5). But incorporating its importance in forecasting aiming to be approach in two ways, which we will call structural and phenomenological. In the structural approach the underlying processes are understood and modelled. The biological details are modelled and their effects are accumulated; temperature on egg production, then temperature on eggs survival, etc. An example of the phenomenological approach would be to add a temperature factor to stock and recruit data and to a statistical analysis of its importance, without inquiring into the mechanisms. This second approach requires less work but is less informative. A preliminary analysis of the influence of temperature on in a stock recruit model (age 0 recruits as a Ricker function of biomass and bottom temperature in Sub-division 25) suggested that temperature did not explain much of the variation. (See Figure 3.1)

For the processes for which there is less or noisier data., Bayesian and non-parametric methods may be required. Examples of these approaches used in noisy stock recruit data are Getz and Swartman (1981) who developed a non-parametric model, which essentially divides the data into a few areas and looks at their means. Mackinson *et al.* (1999) develop “model free estimation” for stock-recruit data using a fuzzy logic approach. An example of Bayesian approach in relation to stock-recruit relationships may be seen in Liermann and Hilborn (1997) and a preliminary example is presented in Section 4.

And finally, when there is no supporting data but reason to believe that environmental forcing may be factor inferences may be drawn from meta-analysis or other stocks. This approach is probably just suitable for sensitivity analysis in which the question of the following sort are posed: If an X% change in temperature (or any other environmental factor) affects a life history parameter by Y% what is the impact on short term yield. This type of analysis can lead to identification of critical gaps in knowledge and research planning.

Presuming that the causal relationships can be found, there is still the problem of predicting the environmental factors. Environmental predictions of more than a year would be difficult. The North Atlantic Oscillation, which in turn influences currents and temperatures, for example is highly variable from one year to the next. Figure 3.2.

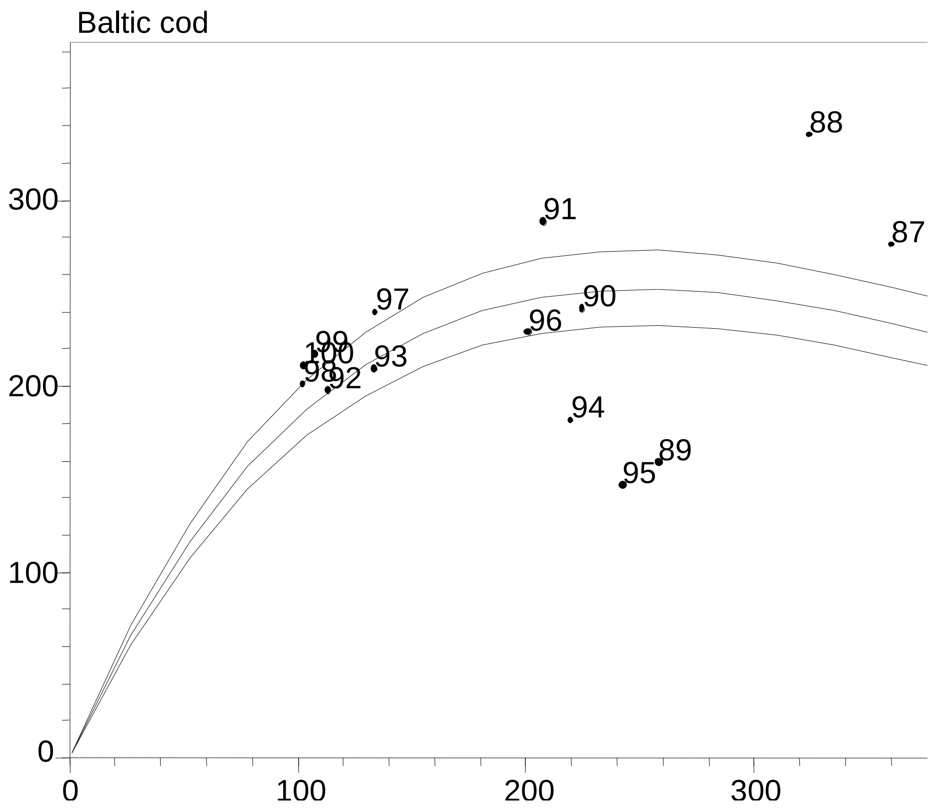


Figure 3.1 Affect of temperature on Baltic cod recruitment from a phenomenological model. The line in the center is the best fit to the data and the upper and lower lines are the estimate of the impact of a year 2 degrees above or below normal.

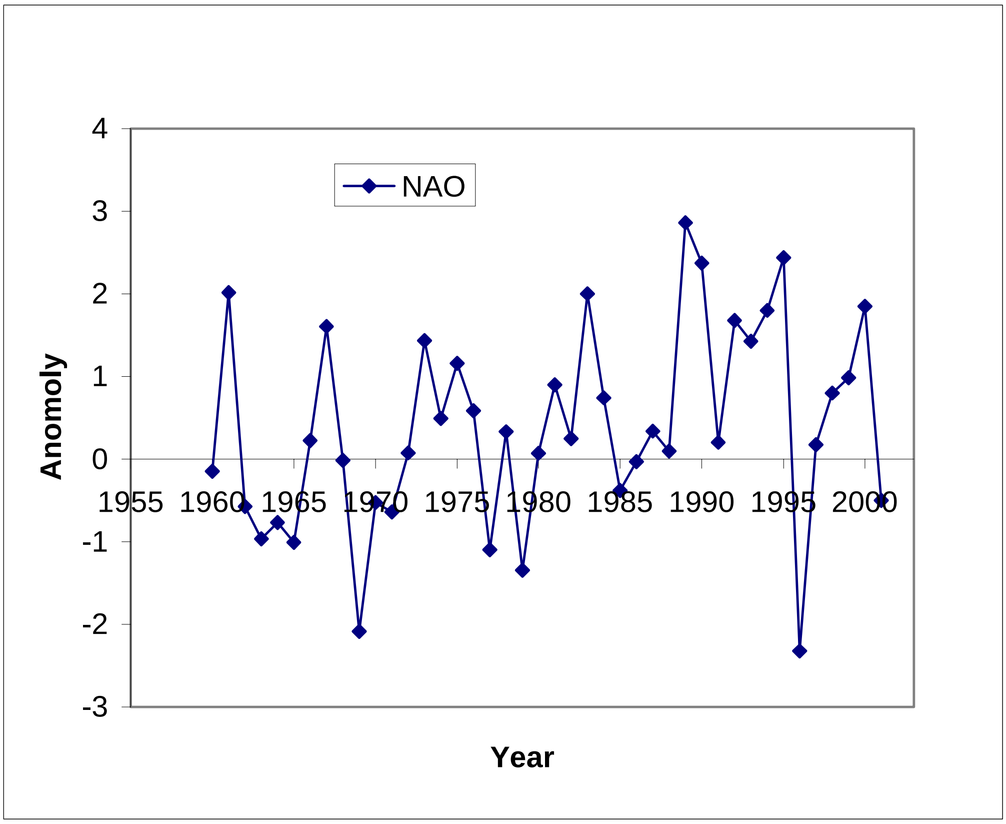


Figure 3.2 North Atlantic Oscillation from 1960 to 2001.

4 THE 4M PACKAGE AND PACKAGE TESTING

The 4M software package (Vinther *et al.*, 2001) was applied to make a MSVPA "key-run" for the cod, sprat and herring in the Central Baltic for the period 1974–2000. This run estimates natural mortality for use in the single species assessment WG. Four scenarios were furthermore set-up to test the forecast mode of 4M.

4.1 MSVPA Key-Run

MSVPA set-up

Following basic input data have been used for the MSVPA key-run:

- catch at age and weight at age in the catch and in the stock as outlined in Section 2,
- quarterly cod stomach content data (1977–93) by Sub-division as revised previously (ICES 1997/J:2), intra-cohort cannibalism of cod was excluded by changing prey age to predator age minus 1 and omitting cod in 0-group cod stomachs,
- maturity ogives for cod in different Sub-divisions represent averages over the periods 1980–84 (applied also prior 1980), 1985–89, 1990–94 and annual data for 1995–99 for combined sexes as presented in single species assessment (ICES 1998/ACFM:16; ICES 2000/ACFM:14), and for 2000 an average over the years 1997–1999 as utilized by the Assessment WG; for sprat and herring maturity ogives were used as given in ICES (1998/ACFM:16) being constant over the entire period,
- suitability sub-model as introduced in ICES (1992/Assess:7),
- quarterly consumption rates for cod as revised in Section 2,
- residual mortalities of 0.2 per year, equally distributed over quarters,
- a constant biomass of other food,
- oldest age-groups in the analyses were: 8+ for cod, 8+ for herring and 7 for sprat.

The terminal F-tuning of MSVPA was performed with the new 4M-programme routine developed and implemented iteratively running XSAs and MSVPAs (Vinther, 2001). XSA settings were identical to the ones used in assessment runs by Baltic Fisheries Assessment Working Group (ICES 2001/ACFM:18). Fishing mortalities in the terminal year for the 0-groups (and the 1-group for cod) are not estimated in the XSA tuning and values were given such that the final estimated MSVPA stock numbers of cod and herring were close the average values estimated in period 1995–1999. For sprat the terminal F was given such that the estimated stock numbers of 0-group follows a similar pattern as estimated by the single species RCT3 analysis done by the assessment WG (ICES 2001/ACFM:8).

Results of the key run

The main results of the MSVPA key-run for the Central Baltic are given in summary Figures 4.1.1–4.1.3.

The spawning stock biomass of Eastern Baltic **cod** derived by the MSVPA run shows a pronounced increase from 1977 to 1980, remaining on a high level during the first half of the 1980s, afterwards declining to lowest level on record in 1992, showing a restricted intermediate increase in the mid 1990s being presently close to the historic minimum. This is well in agreement with the respective estimates from single species VPA (ICES 2001/ACFM:18), see Figure 4.1.4. Higher deviations between standard and multispecies SSB estimates are obvious for the beginning of the 1980s. These differences are caused by lower mean weight at age in the stock applied in the MSVPA runs, as derived stock numbers are rather similar for age-groups 2+. Furthermore, it should be mentioned that in the MSVPA runs catch at age from Sub-divisions 30 and 31 were not included, which were higher in the 1980´s compared to later years. After 1993, when the input data sets deviate only to a minor extent, the estimated biomass values are very well in agreement. To get a further indication of the reliability of the MSVPA, abundance indices of age-group 2+ from the international bottom trawl surveys were correlated to corresponding MSVPA estimates. These estimates are not independent, as survey results were utilized for tuning, however, a comparison throughout the 1980s should be possible, as the impact of the tuning survey on the stock estimate reduces when going back in time. In fact both abundance time series are highly correlated (Figure 4.1.5). Repeating the exercise for recruitment estimates at age 2 showed a good agreement between MSVPA and single species output (Figure 4.1.6). Fishing mortality rates determined by MSVPA and the standard assessment show similar time pattern, with the single species assessment estimating in general slightly higher values (Figure 4.1.7). An exceptional high fishing mortality in the MSVPA output in 1989 is probably caused by missing records in the catch data set for age-group 7 in the 3rd and 4th quarter of 1990, although in the same cohort in previous and following years catches were recorded. As a result fishing mortality in age-group 6 in the 4th quarter 1989 exceeded 1.5. Correspondingly the mean fishing mortality in 1990 from MSVPA is somewhat lower than in the single species VPA. Predation mortalities of 0-, 1- and 2-group cod (Figure 4.1.8) are in the same order of magnitude than derived by earlier MSVPA runs. The intensity of cannibalism on 0-group cod in 1974–1976, is somewhat astonishing, as the predator abundance is considerably lower than in early 1980s. Estimated predation mortalities of 1- and 2-group cod follow more closely the development of the predator stock size.

The estimated spawning stock biomass of **sprat** shows a pronounced decline from the mid 1970s to the early 1980s, a trend that is slightly less pronounced in the standard assessment (Figure 4.1.4). In fact the mid 1970s exhibit largest deviations between both assessments, i.e., in 1974 and 1975 the MSVPA based estimates are considerably higher than the standard XSA output. The subsequent increase of the spawning stock from the late 1980s to historically high levels of around 1.9 million t. in 1997 is shown by both assessments, with the MSVPA estimating slightly higher SSB values. The described deviations between spawning stock biomass values are caused to some degree by different weight at age, as determined stock numbers are rather similar from 1977–1999. Deviations in 1974–1976 are in contrast not entirely explained by deviations in weight at age, but by differences in catch at age, being higher in the multispecies database in 1974 and 1975. Correspondingly deviations in sprat recruitment estimates are apparent especially for these early years of the time series (Figure 4.1.6) Correlating the MSVPA derived sprat stock size (age-group 1+) with the abundance estimate from the tuning fleet covering the longest time span, i.e., the Latvian/Russian hydroacoustic survey in Sub-divisions 26 and 28, revealed a very close agreement, with the exception of an outlying hydroacoustic survey estimate in 2000, see Figure 4.1.5. Especially the extraordinary high hydroacoustic abundance estimate in Sub-division 29 and 32 caused this deviation. The MSVPA derived fishing mortality rates follow rather well the general trend in F estimates from the standard XSA (Figure 4.1.7), with some higher deviations in the periods 1976–1980 and 1989–1992. Predation mortalities of sprat showed a continuous decline from mid 1970s to early 1990s being rather constant afterwards (Figure 4.1.8).

Spawning stock biomass estimates of Central Baltic **herring** derived by the MSVPA run show a continuous decline (Figure 4.1.4), which is however to a large extend caused by reduction in weight at age. A high variability is indicated by the hydroacoustic estimate of age group 1+ (Figure 4.1.5). In contrast to cod and sprat the comparison of stock size estimates from MSVPA and hydroacoustic surveys shows more variability with the hydroacoustic survey indicating a more pronounced intermediate peak of herring abundance in early 1990s. This period is, however, characterized by technical and area coverage problems, which is also the reason for omitting 1992 and 1993 survey results. Similar to sprat the most recent hydroacoustic survey revealed an outstanding high stock size in 2000, with again a very high population size in northern Sub-divisions. Recruitment at age 1 derived by the MSVPA does not show a pronounced peak in the early 1990s, but rather a declining trend since the early 1980s, with outlying low recruitment of the 1985 and 1987 year-class (Figure 4.1.6). In contrast to the good agreement in abundance estimates, the SSB shows larger deviations between the multispecies and the standard assessment (Figure 4.1.4). The reason is a difference in mean weight at age, i.e., the MSVPA uses the mean weight in the 1st quarter, whereas the annual mean weight was applied in the standard assessment. As the latter is 30–50% higher than the mean weights in the 1st quarter (ICES 2001/ACFM:18), the overall biomass estimate derived by MSVPA is correspondingly lower. The estimated fishing mortality rates obtained from MSVPA and standard assessment are rather similar, with largest deviations in 1978 and 1979, both indicating a doubling of fishing mortality from early to late 1990s (Figure 4.1.7). Predation mortality follows closely the time trend described for sprat. However, a substantial difference between the species is, that predation mortalities of adult herring is very low, reaching seldom 0.1 per year (Figure 4.1.8).

Natural mortalities

Natural mortalities estimated by MSVPA are routinely used in the single assessment (ICES 2001/ACFM:8). The values estimated by the last iteration of the multispecies tuning are presented on “Lowestoft” format in Table 4.1.1–4.1.3.

4.2 Multispecies Forecast

The 4M forecast software was used to evaluate different forecast scenarios. These runs were made mainly to test the applicability of the 4M software, however, the output illustrates possible effects of changes in both the fishing pattern and the environment. Four scenarios were set-up:

1. Key-run: Food suitabilities as estimated by the MSVPA key-run and *status quo* fishing mortalities in the prediction. Recruitment estimated from a Ricker SSB-recruitment relationship.
2. Fpa: Similar to the Key-run, but prediction Fs were scaled to Fpa for the three species
3. High cod stock: Stomach data from 1977 to 1983 as input to the suitability calculation. These data contain most of the cod cannibalism observation over the whole time series. Recruitment was estimated from a log-normal distribution fitted to data for the period 1974–1983.

4. Low cod stock: Stomach data from 1984 to 1993 as input to the suitability calculation. Cannibalism observed was rather low. Recruitment was estimated from a log-normal distribution fitted to the period 1984–1999.

Input data to the prediction were derived from the MSVPA. Prediction mean weight in the sea, residual natural mortalities and rations were estimated as average value, 1996–2000, and kept constant in the prediction. *Status quo* fishing mortalities were copied from the year 2000 values. For prediction 1 and 2, food suitabilities were estimated in the MSVPA key-run. Additional multispecies tuned MSVPA was made to estimate the food suitabilities for prediction 3 and 4, using different stomach contents data from the periods specified.

All forecast were made for the period 2001–2031, with stochastic recruitment, repeated 100 times.

4.2.1 Key run and Fpa Forecasts

The key run and the Fpa predictions were made using a Ricker stock recruitment. In 4M, stochastic recruitment is implemented by specifying a recruitment model, the parameter values used, and the CV of the parameters (see ICES1999/H:5). The recruitment model were fitted to MSVPA estimated recruits and SSB data from the period 1987–1999 for cod, and 1974–1999 for sprat and herring, using a non-linear fitting routine (SAS proc Nlin). Spawning was assumed to take place in the first quarter, and recruits are entering the model at age 0, third quarter. The estimated parameter values and CV are given in Table 4.2.1 and Figure 4.2.1 present the fitted recruitment relation and gives examples on recruitment values obtained from the stochastic model.

An alternative apporach to the stock recruitment problem is to apply a Markov chain Monte Carlo algorithm (MCMC) to explore the characteristics of parameter space. This method takes random steps in the parameter space and decides the next step with a probabalistic decision based on its likelihood. Data was used for Baltic cod from 1987 to the present and a standard 2 parameter Ricker model. Figure 4.2.2 shows the path of the MCMC trials. 2500 steps were performed but only every fourth one was retained to reduce serial correlation. The plot shows the interdependence of the two parameters. In Figure 4.2.3 the marginal distributions for the two parameters are presented and neither distribution appears to be normal; parameter a is skewed to the right and parameter b is bimodal. The following Figure (4.2.4) shows the minima in the likelihoods for each and Figure 4.2.5 shows the best fit through the original data and the results of 200 draws from the MCMC output. Compared to the recruitment pattern used in the predictions (Figure 4.2.1), which shows similar draws assuming a normal noise distribution, the MCMC recruitment draws tend to be lower at low SSB than the fitted stock recruitment relation for the observed SSB values. This is probably a result of autocorrelation in the Ricker parameter estimates.The implication of this autocorrelation is that the stock recruitement relation used in prediction may give rather optimistic estimates on cod recruitment when SSB is at lower values.

In the Fpa forecast, the *status quo* F were scaled to Fpa using the factors presented in Table 4.2.2.

Forecast results

The key-run prediction results are presented in Figure 4.2.6. For each species the average annual values of the 100 predictions of total stock biomass (1. Jan) and the SSB are given with the 95% confidence limits. The annual yield, the biomass eaten by the MS species (Cod), and the biomass “removed” by other causes of death are presented in a similar way. Finally a frequency plot presents the 1-group, 1 Jan. distribution.

At *status quo* fishing mortality, the biomass and yield of cod and sprat will remain at the present level, while the biomass of herring will be reduced by 50% after 30 years due to the relatively high *status quo* F for herring (Table 4.2.2).

The prediction using Fpa values estimates a steep increase in the cod biomass in the first 7–8 years, however the SSB will remains lower than Bpa (Figure 4.2.7). Herring biomass will more than double and become higher than Bpa during the 30 years prediction mode, due the substantial reduction in fishing mortality. Fpa for sprat is higher than *status quo* F, which in combination with an increasing cod predation leads to a declining sprat biomass.

4.2.2 High cod stock and low cod stock forecasts

The periods 1969–1975, 1976–1979 and 1980–1990 differ in major oceanographic characteristics and in cod recruitment (Matthaus *et al.*, 1992; Anon., 1997):

- **1969–1975**. The inflows of high-saline waters were intense and short-time stagnation is observed below the halocline. The recruitment and biomass of cod were relatively stable.

- **1976–1983**. Oxygen and salinity conditions in the near bottom water layers were favourable for cod reproduction. The highest inflow was observed in 1977. The abundance of cod increased sharply due to successful recruitment.
- **1984–2000**. A period of deep-water stagnation. The biomass of cod reached maximum in the early of 1980s and decreased rapidly from 1986.

Abundant cod generations were observed in 1964, 1967, 1969, 1972, 1976, 1977, 1980 and 1981 (Netzel, 1974; Lablaika *et al.,* 1975; Plikshs *et al.,* 1993).

During the period of deep-water stagnation, fishing pressure on cod was constantly high. This combination had three consequences:

- a **decrease in the predator stock** and a concurrent increase in sprat stock size (the major prey species of cod in the Central Baltic) following the hypothesis, that cannibalism occurs especially in times of limited food availability of preferred prey species (e.g., as has been hypothesized for North East Arctic cod by Mehl 1989),
- a **shift in predators horizontal distribution**, i.e., the diminishing of the cod in the Gotland Basin, while the remaining stock concentrated in the Bornholm Basin and the Gdansk Deep, where cannibalism may be less intense due to limited overlap of predator and prey, as demonstrated by Uzars (1995) for the latter area,
- a **shift in the vertical distribution of predatory cod** to a more pelagic mode of life in and around the main Baltic basins, as oxygen conditions were increasingly unfavourable during the stagnation period (Plikshs *et al.* 1990, Tomkiewicz *et al.* 1996), while juvenile cod were probably avoiding these areas, due to the limited food supply. This implies reduced cannibalism.

The considerable changes in the relative distribution of adult cod and their potential prey occurred in relation to the decline of the Central Baltic stock may violate the assumption that an average suitability coefficient calculated for the entire period reflects the mean relative spatial distribution of predator and prey.

To elucidate the specific situation for the stomach data and predator stock age structure in the Central Baltic Sea, comparative test runs of the MSVPA have been performed previously (ICES 1999/H:5) and repeated during this Working Group as well with the updated data. The stomach data sets for the comparative runs were:

High cod stock:	Stomach data from 1977 to 1983 as input to the suitability calculation.
	These data contain most of the cannibalism observation over the whole time series.
Low cod stock:	Stomach data from 1984 to 1993 as input to the suitability calculation.
	Cannibalism occurs rather seldom in these data

Mainly the 0-group cod was subject to changing suitability in the different runs. The usage of the stomach data from before 1984 revealed a suitability coefficient which is about 8 times higher than the coefficient derived by using the stomach data from the second period, which contained clearly less cannibalism observations.

Up to predator age 4 there was no major difference, but from age 6 onwards the usage of the 1977–1983 stomach data set generated clearly higher suitabilitites of 0-group cod.

The predation mortalities for 0-group cod in the fourth quarter were however by far not as much deviating, as one would expect looking at the large differences in the suitability coefficients. Although in 1984 the difference between the two set-ups was about 40%, deviation does in general not exceed 20% and from 1987 onwards even 10%. This feature of the MSVPA is to a large extent explainable by the development of the age structure of the predator stock in the Central Baltic. Cod older than 5 has always been on a low level. Hence, the ration of the total 0-group cod consumed from the predators older than 5 was minor over the whole time series. Since the major deviation in prey suitabilities stems from these predator age groups, the deviation in suitabilities is compensated in the case of Central Baltic cod and the generated predation mortalities were relatively stable.

Forecast results

The “High cod stock” prediction, with a relatively high cod recruitment and cannibalism level shows a remarkable fast increase in the cod biomass (Figure 4.2.8). The highest cod biomass is achieved in the beginning of the prediction period with very few older cod and thereby a limited cannibalism. The effect of cod cannibalism might cause the oscillations seen for the biomass. With the high recruitment level, the cod biomass remains higher than B_{pa}, even though *status quo* F is used. The biomass of sprat and herring follows the oscillations in the cod biomass due to predation.

Herring biomass is slightly reduced, but the cod predation diminishes the sprat biomass to approximately one third of the initial value for the prediction.

In the “Low cod stock” prediction (Figure 4.2.9) cod biomass increases to a slightly higher level than the initial level. This is probably a result of a relatively high recruitment for the 1984–1985 year-class, which was included in the data used to fit the log-normal distribution of recruits used in the prediction. The biomass of herring remains at the initial level for the prediction while the sprat biomass is slightly reduced.

Table 4.1.1 Natural mortalities of Cod estimated by multispecies tuning.

```
Natural mortality at age; Cod in the Eastern Baltic (25–32)
1 5
1966 2000
2 8
1
0.2 0.2 0.2 0.2 0.2 0.2 0.2
0.2 0.2 0.2 0.2 0.2 0.2 0.2
0.2 0.2 0.2 0.2 0.2 0.2 0.2
0.2 0.2 0.2 0.2 0.2 0.2 0.2
0.2 0.2 0.2 0.2 0.2 0.2 0.2
0.2 0.2 0.2 0.2 0.2 0.2 0.2
0.2 0.2 0.2 0.2 0.2 0.2 0.2
0.2 0.2 0.2 0.2 0.2 0.2 0.2
 0.243748 0.204421 0.200698 0.200046 0.200003 0.200001 0.200000
 0.275794 0.208599 0.201441 0.200094 0.200007 0.200002 0.200000
 0.262733 0.208548 0.201653 0.200117 0.200009 0.200002 0.200000
 0.248099 0.206080 0.201136 0.200077 0.200007 0.200002 0.200000
 0.254576 0.206308 0.201115 0.200080 0.200006 0.200001 0.200000
 0.284495 0.209526 0.201630 0.200107 0.200011 0.200003 0.200000
 0.306200 0.212702 0.202036 0.200124 0.200008 0.200002 0.200000
 0.289100 0.212145 0.202294 0.200147 0.200011 0.200002 0.200000
 0.296670 0.212207 0.202330 0.200169 0.200014 0.200004 0.200000
 0.316039 0.215020 0.202825 0.200211 0.200021 0.200003 0.200000
 0.286412 0.212524 0.202419 0.200162 0.200016 0.200005 0.200000
 0.274429 0.210941 0.202193 0.200149 0.200014 0.200005 0.200000
 0.241572 0.204957 0.200864 0.200059 0.200004 0.200001 0.200000
 0.226819 0.203765 0.200791 0.200060 0.200006 0.200002 0.200000
 0.236081 0.204853 0.200970 0.200070 0.200007 0.200002 0.200000
 0.226729 0.203913 0.200806 0.200060 0.200006 0.200002 0.200000
 0.215192 0.201633 0.200254 0.200016 0.200001 0.200000 0.200000
 0.215082 0.202524 0.200595 0.200048 0.200005 0.200002 0.200000
 0.209055 0.200927 0.200144 0.200010 0.200001 0.200000 0.200000
 0.210033 0.201101 0.200201 0.200015 0.200001 0.200001 0.200000
 0.215180 0.201766 0.200328 0.200024 0.200002 0.200001 0.200000
 0.218773 0.202375 0.200443 0.200032 0.200003 0.200001 0.200000
 0.213993 0.201531 0.200257 0.200017 0.200001 0.200000 0.200000
 0.216637 0.202216 0.200447 0.200035 0.200004 0.200001 0.200000
 0.214188 0.201930 0.200396 0.200030 0.200003 0.200001 0.200000
 0.212035 0.201446 0.200292 0.200022 0.200002 0.200001 0.200000
 0.210924 0.201257 0.200233 0.200017 0.200002 0.200001 0.200000
```

Table 4.1.2 Natural mortalities of Herring estimated by multispecies tuning.

```
Natural Mortality, herring SD 25–29 (incl Gulf of Riga) and SD 32
1 5
1974 2000
1 8
1
 0.630418 0.335290 0.290495 0.258105 0.256702 0.239320 0.233984 0.210487
 0.787368 0.356719 0.309025 0.272991 0.270686 0.248500 0.241700 0.212742
 0.565779 0.317663 0.285393 0.257262 0.254308 0.238311 0.232214 0.209762
 0.516348 0.297057 0.273265 0.249975 0.248104 0.234512 0.228370 0.208600
 0.660666 0.336098 0.297756 0.264935 0.262752 0.244581 0.237103 0.211323
 0.830786 0.381233 0.334657 0.289654 0.284325 0.259919 0.249171 0.214750
 0.864497 0.378321 0.334558 0.290507 0.283644 0.259075 0.248354 0.214369
 0.743734 0.358477 0.322422 0.285338 0.281680 0.256753 0.246335 0.213961
 0.823160 0.385183 0.344380 0.299907 0.295492 0.269045 0.255662 0.216790
 0.840396 0.402407 0.355635 0.308024 0.304340 0.273937 0.261499 0.218649
 0.659339 0.335708 0.309899 0.277233 0.272524 0.251362 0.240738 0.212071
 0.567453 0.308557 0.287016 0.261207 0.257588 0.240837 0.232832 0.209778
 0.462585 0.274879 0.257333 0.239645 0.238028 0.227087 0.222234 0.206713
 0.384593 0.256447 0.241846 0.228512 0.227662 0.219589 0.216120 0.204901
 0.430873 0.261926 0.245417 0.231202 0.229753 0.220493 0.216901 0.205084
 0.358777 0.244523 0.233652 0.223039 0.221709 0.215249 0.212418 0.203708
 0.312334 0.231649 0.222918 0.215559 0.215145 0.210545 0.208942 0.202736
 0.277681 0.222208 0.216667 0.211582 0.210994 0.207795 0.206361 0.201907
 0.276122 0.222315 0.216122 0.210554 0.209957 0.207184 0.205991 0.201814
 0.283575 0.226633 0.218893 0.212880 0.213031 0.209033 0.207812 0.202434
 0.305862 0.230776 0.222667 0.215673 0.215289 0.210641 0.208958 0.202739
 0.302652 0.235814 0.228316 0.219975 0.219490 0.213872 0.211627 0.203554
 0.282094 0.229906 0.223545 0.216239 0.215682 0.211405 0.209494 0.202896
 0.288618 0.229891 0.223467 0.216282 0.215554 0.211351 0.209312 0.202817
 0.292578 0.228608 0.221330 0.214800 0.214432 0.210235 0.208493 0.202599
 0.298983 0.227596 0.219131 0.212652 0.212217 0.208605 0.207231 0.202208
 0.288702 0.226706 0.218827 0.212723 0.212561 0.208609 0.207415 0.202288
```

Table 4.1.3 Natural mortalities of Sprat estimated by multispecies tuning.

```
Natural Mortality, Sprat in Sub-divisions 22 to 32
1 5
1974 2000
1 8
1
 0.975161 0.594547 0.473478 0.450514 0.532327 0.488865 0.551753 0.551753
 1.373457 0.765604 0.581863 0.535835 0.646475 0.613888 0.708305 0.708305
 0.837995 0.530393 0.422194 0.399584 0.473547 0.460505 0.526917 0.526917
 0.756138 0.498573 0.415799 0.385011 0.440319 0.434453 0.495112 0.495112
 1.001911 0.648228 0.530555 0.478545 0.557159 0.541726 0.616625 0.616625
 1.189465 0.807184 0.655259 0.573709 0.683841 0.694647 0.795504 0.795504
 1.277415 0.856287 0.686074 0.584302 0.700812 0.749167 0.862206 0.862206
 1.030442 0.712702 0.580547 0.517407 0.609818 0.622964 0.723843 0.723843
 1.157994 0.800306 0.656610 0.570806 0.673550 0.687927 0.801812 0.801812
 1.088522 0.792649 0.641088 0.578532 0.708895 0.708187 0.827195 0.827195
 0.822419 0.634105 0.530463 0.469543 0.547081 0.578950 0.668638 0.668637
 0.728330 0.539958 0.455002 0.409488 0.473470 0.499293 0.571089 0.571088
 0.633974 0.449041 0.382750 0.353361 0.398328 0.400257 0.448706 0.448706
 0.495833 0.374646 0.329741 0.312331 0.344542 0.337522 0.370669 0.370669
 0.557219 0.424196 0.363347 0.338180 0.381039 0.380984 0.418156 0.418156
 0.452048 0.356991 0.316015 0.294966 0.324110 0.328970 0.356902 0.356902
 0.387129 0.308360 0.279079 0.267260 0.287785 0.284827 0.303422 0.303422
 0.327650 0.272780 0.251945 0.244874 0.258926 0.260241 0.273769 0.273769
 0.340107 0.269623 0.250773 0.242163 0.253959 0.254538 0.265448 0.265448
 0.339147 0.280850 0.257942 0.252612 0.270006 0.259419 0.274031 0.274031
 0.363728 0.298756 0.271432 0.262287 0.282490 0.278792 0.295394 0.295394
 0.337071 0.286367 0.264296 0.256559 0.277051 0.276841 0.294907 0.294907
 0.310828 0.267326 0.251516 0.244166 0.259793 0.261020 0.275040 0.275040
 0.330870 0.274812 0.255415 0.247958 0.264144 0.266520 0.281898 0.281898
 0.349279 0.284102 0.260474 0.253448 0.269895 0.267089 0.282432 0.282432
 0.373918 0.294272 0.267658 0.259004 0.276083 0.271556 0.286033 0.286033
 0.343460 0.283166 0.259562 0.253198 0.270912 0.264009 0.277378 0.277378
```

Table 4.2.1 Estimated parameters in the Ricker SSB/recruitment relation used in predictions 1 and 2.

	alfa		*beta*	
	Value	CV %	Value	CV%
Cod	3.08	16	4.64E-9	18
Herring	39.9	18	4.17E-10	30
Sprat	150.5	34	3.24E-10	79

Table 4.2.2 F *status quo* compared to F precautionary (Fpa) approach.

Species	Fsq	Fpa	F-factor
$Cod_{4\text{–}7}$	1.080	0.70	0.65
$Herring_{3\text{–}6}$	0.469	0.17	0.36
$Sprat_{3\text{–}5}$	0.338	0.40	1.18

Figure 4.1.1 Key-run summary.

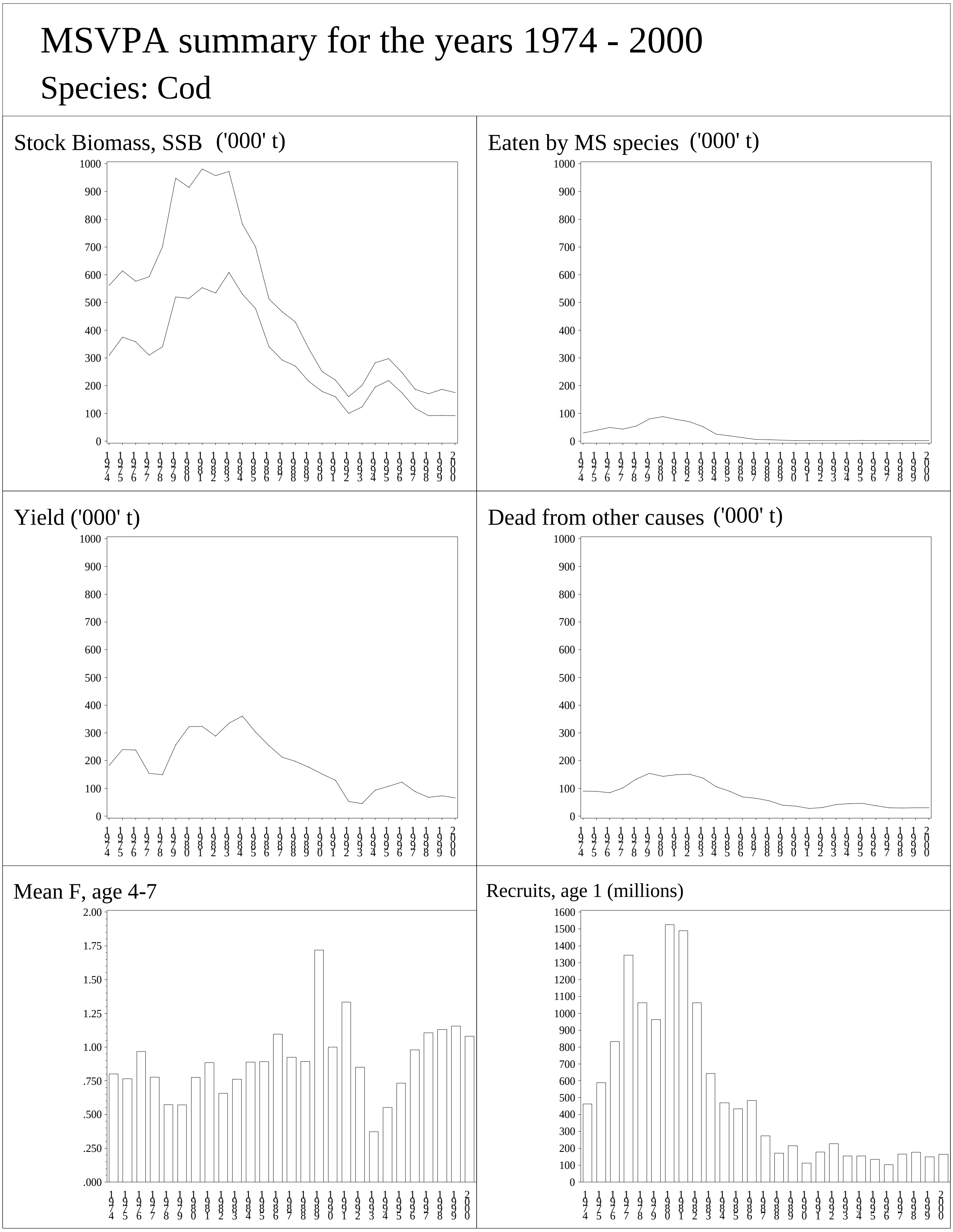


Figure 4.1.2 Key-run summary.

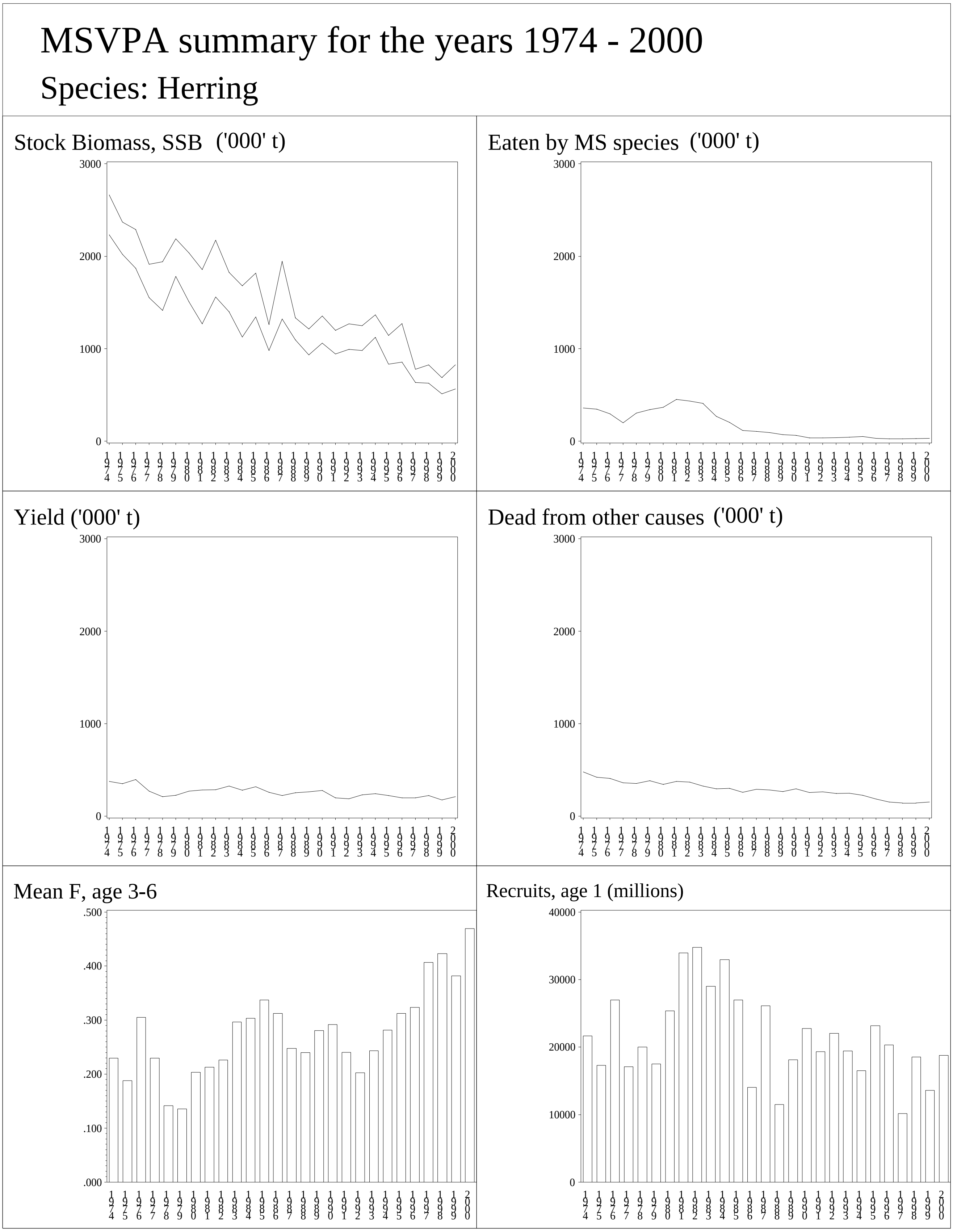


Figure 4.1.3 Key-run summary.

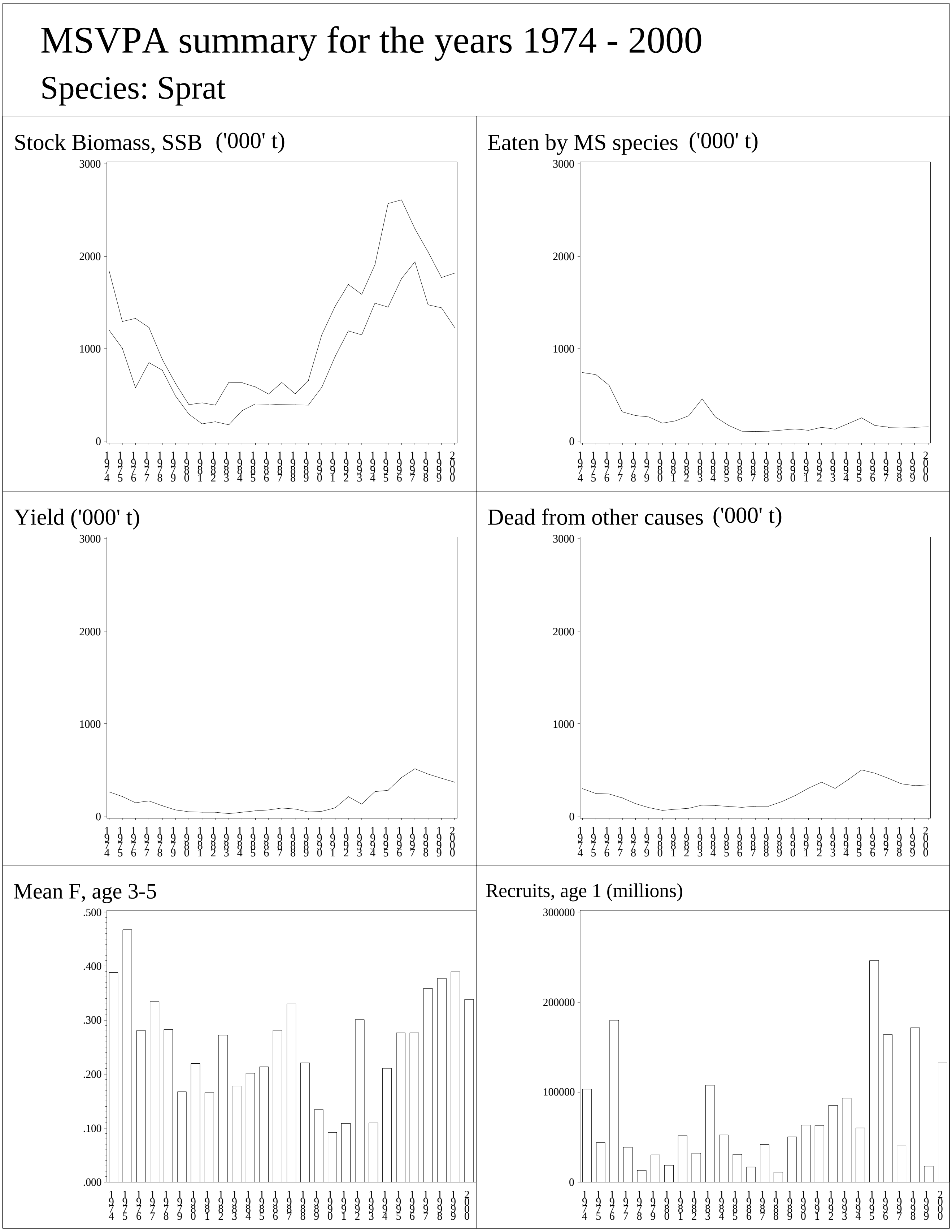


Figure 4.1.4 Times-series of spawning stock biomass (SSB, 1st quarter) of cod, herring and sprat in the Central Baltic Sea derived from MSVPA and standard assessment (SVPA).

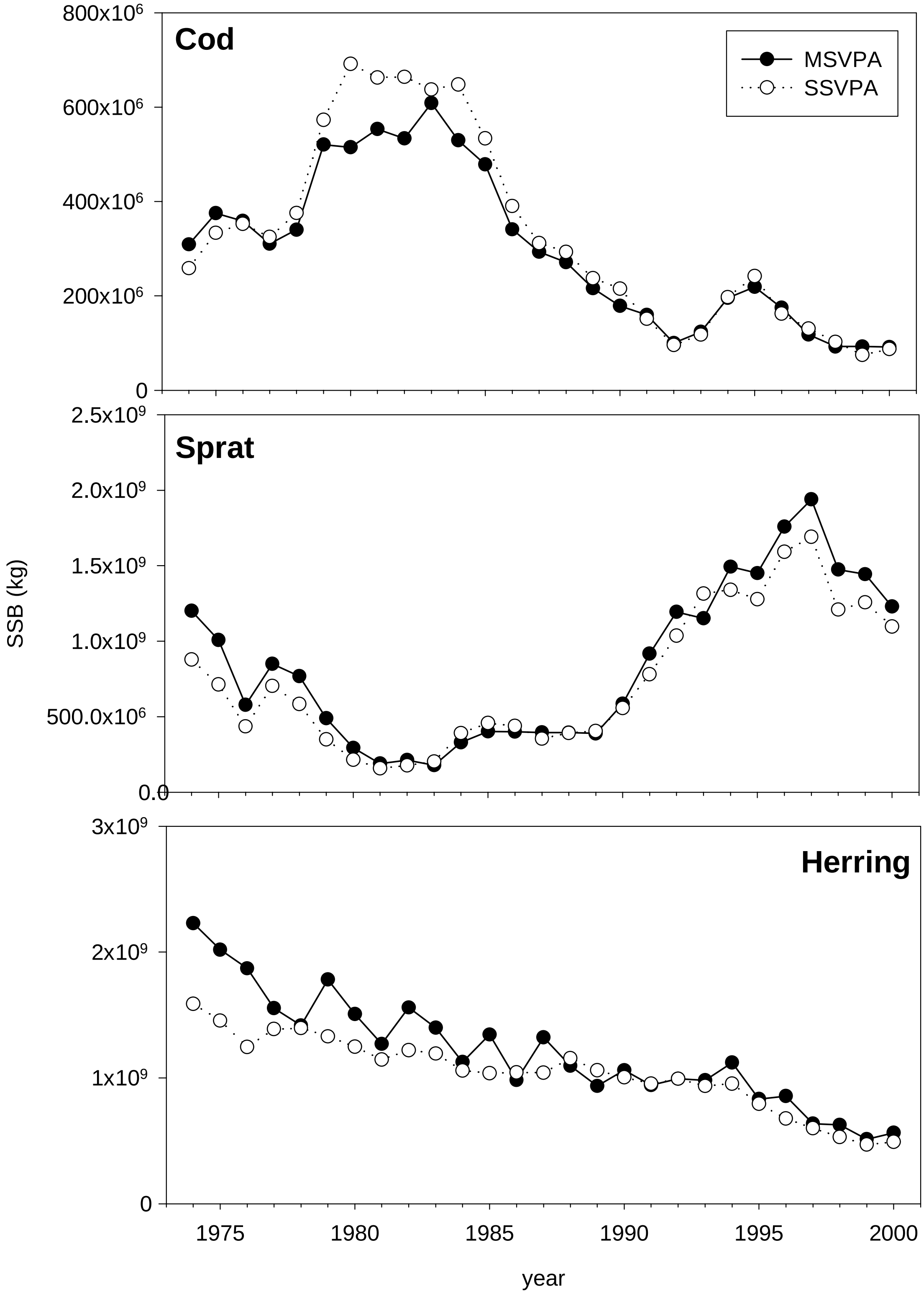


Figure 4.1.5 Comparisons of stock sizes (1st quarter) from MSVPA for cod, herring and sprat with survey data used for tuning (cod: Baltic International Trawl Survey, BITS; herring and sprat: International Hydroacoustic Survey). Left panels: Correlations, right panels: time-series.

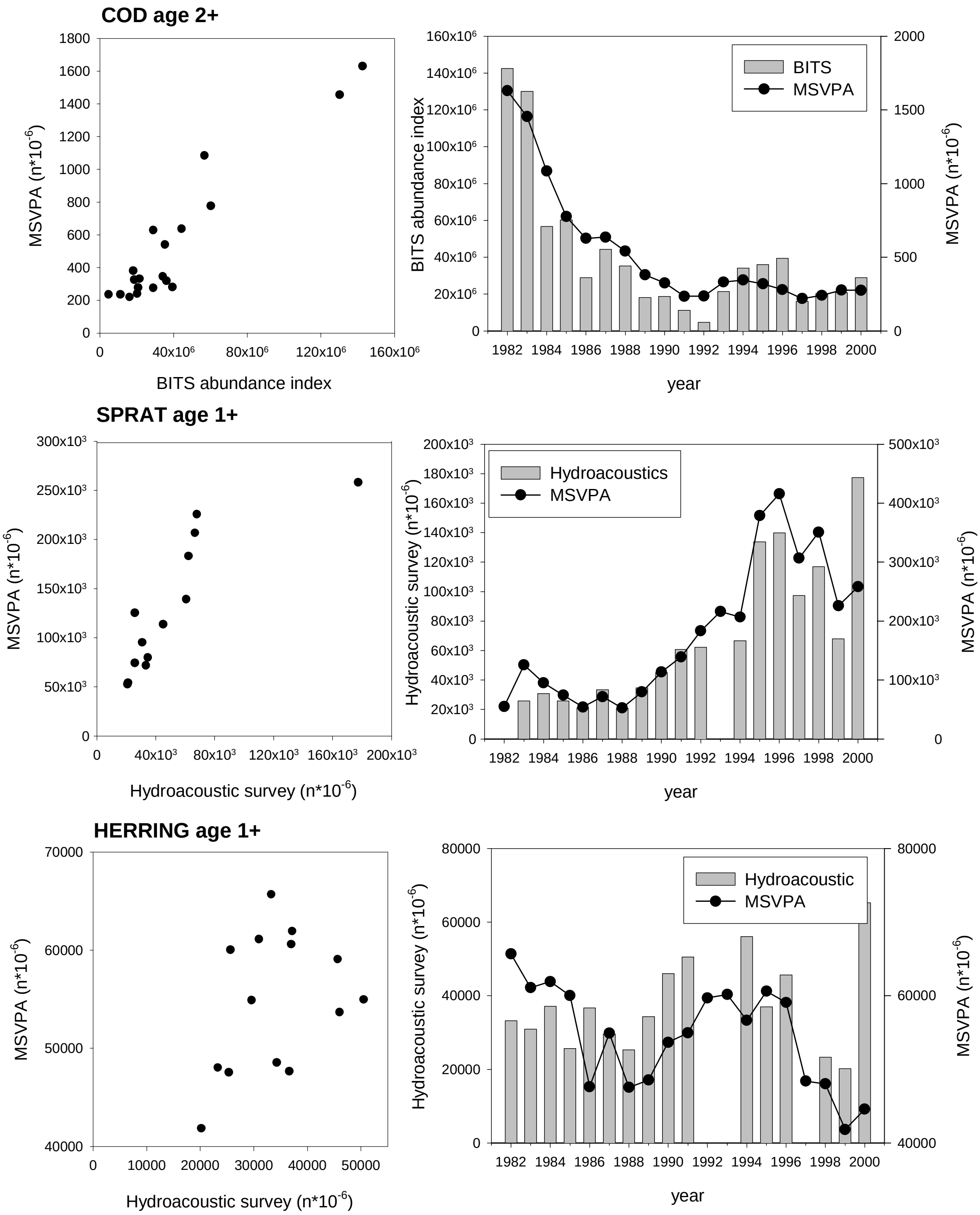


Figure 4.1.6 Time-series of recruitment estimates (1st quarter) of cod, herring and sprat in the Central Baltic Sea derived from MSVPA and standard assessment (SSVPA).

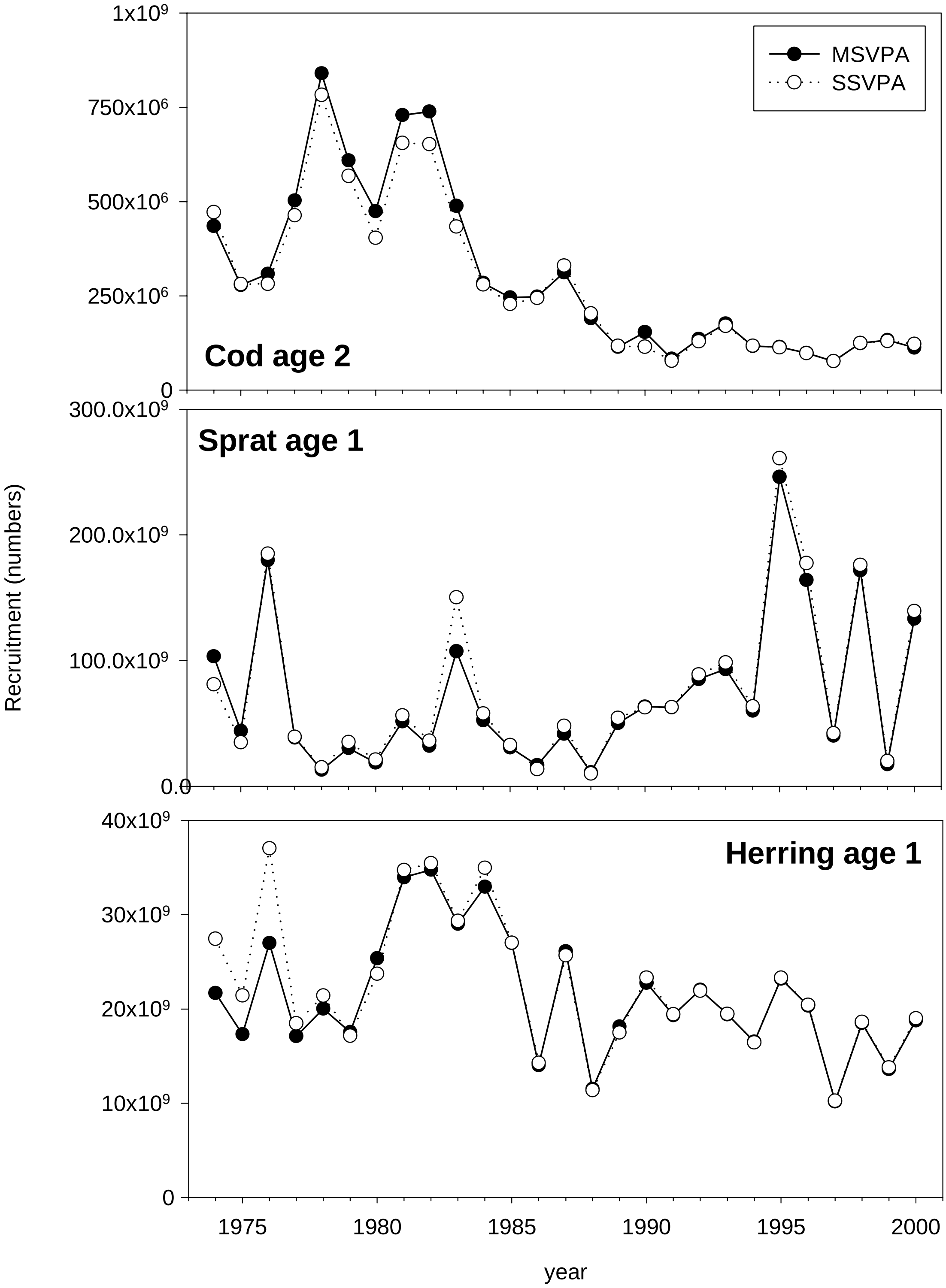


Figure 4.1.7 Time-series of annual fishing mortalities of cod, herring and sprat in the Central Baltic Sea derived from MSVPA and standard assessment (SSVPA).

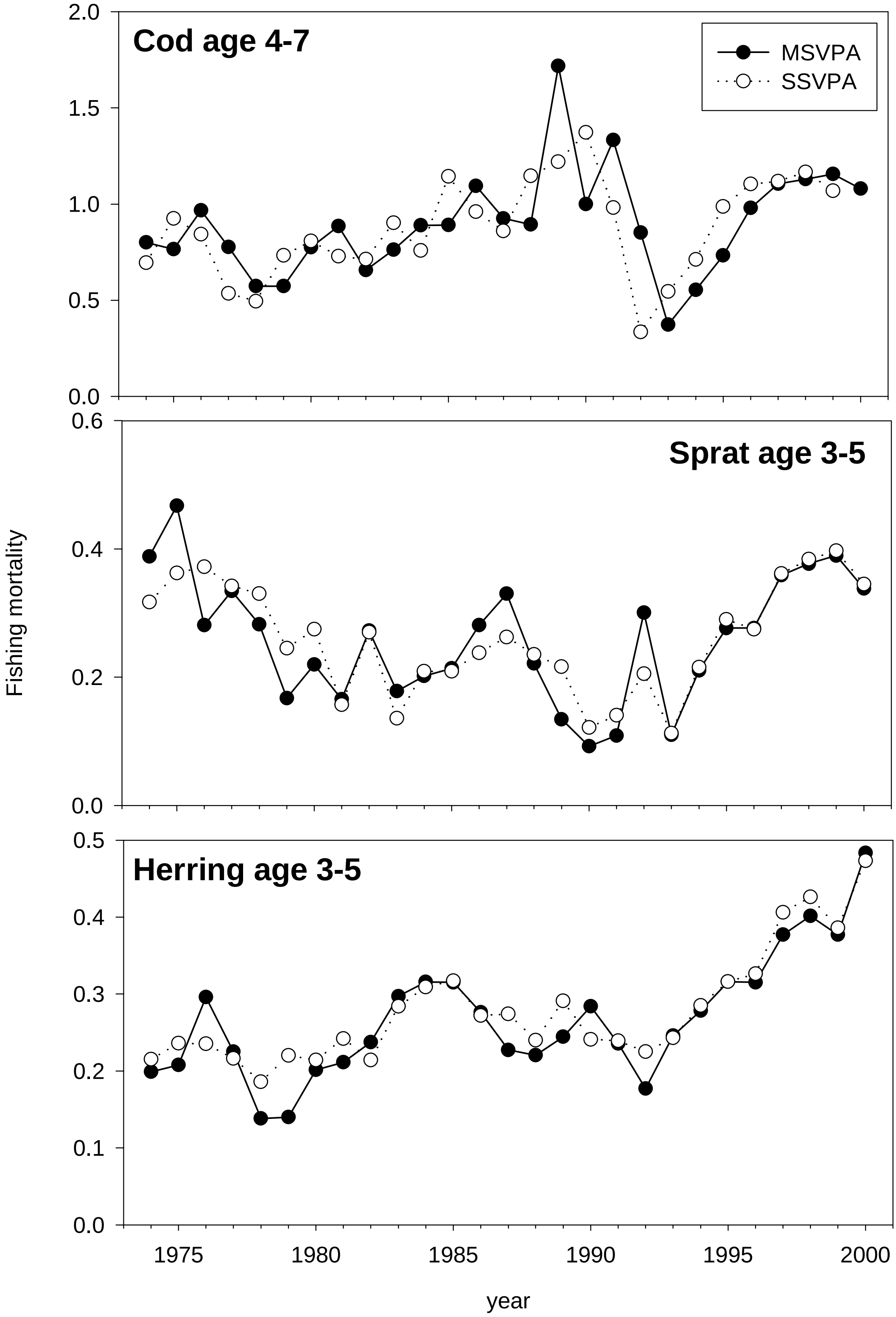


Figure 4.1.8 Time-series of annual predation mortalities of cod, sprat and herring in the Central Baltic Sea derived from MSVPA.

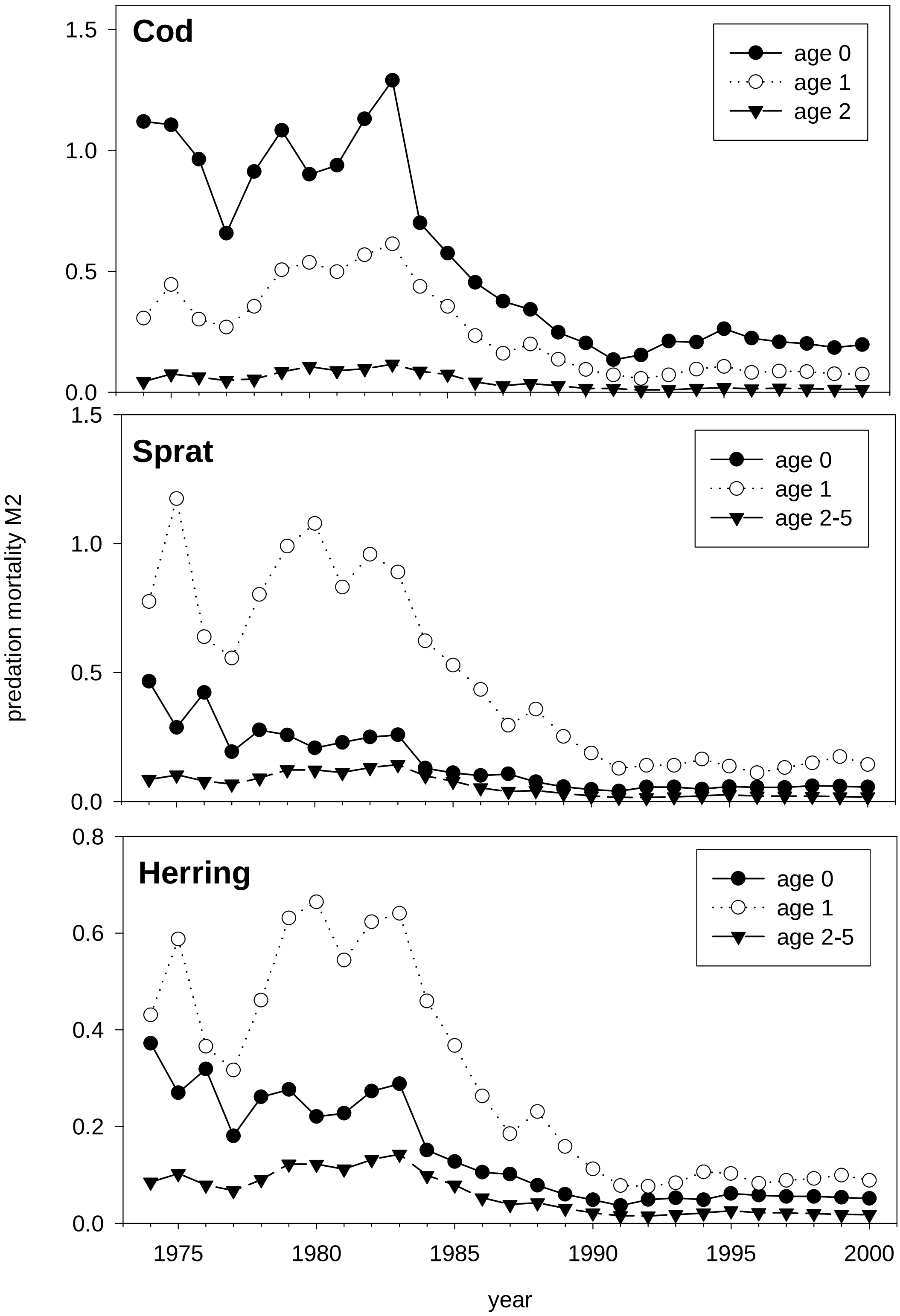
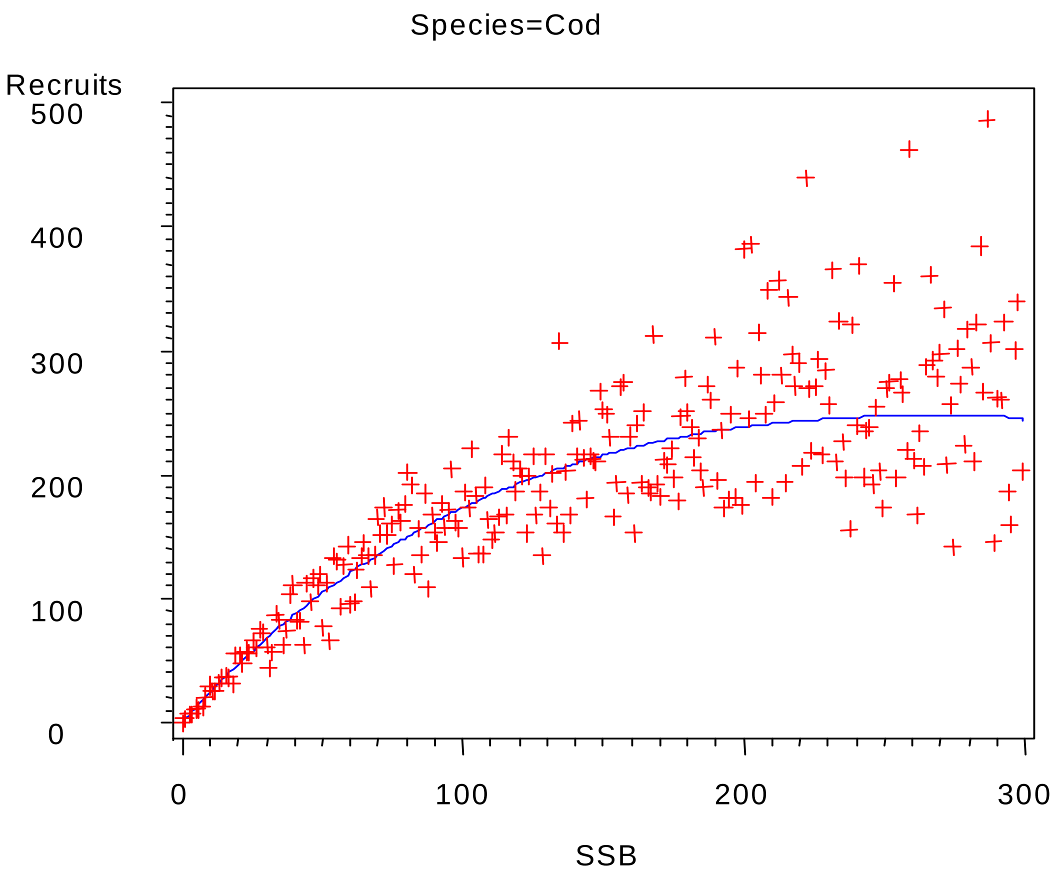


Figure 4.2.1 Simulated spawning stock biomass (1000t) and recruits (millions), relations used in predictions.



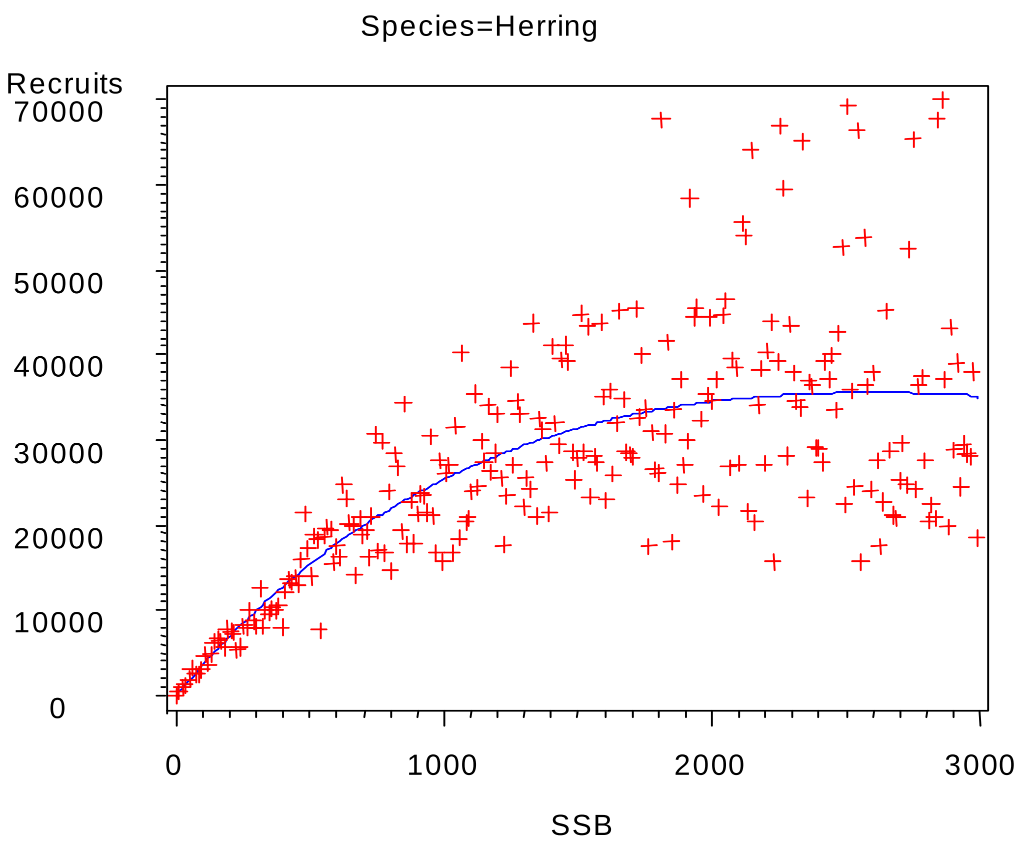


Figure 4.2.1 (continued). Simulated spawning stock biomass (1000t) and recruits (millions), relations used in predictions.

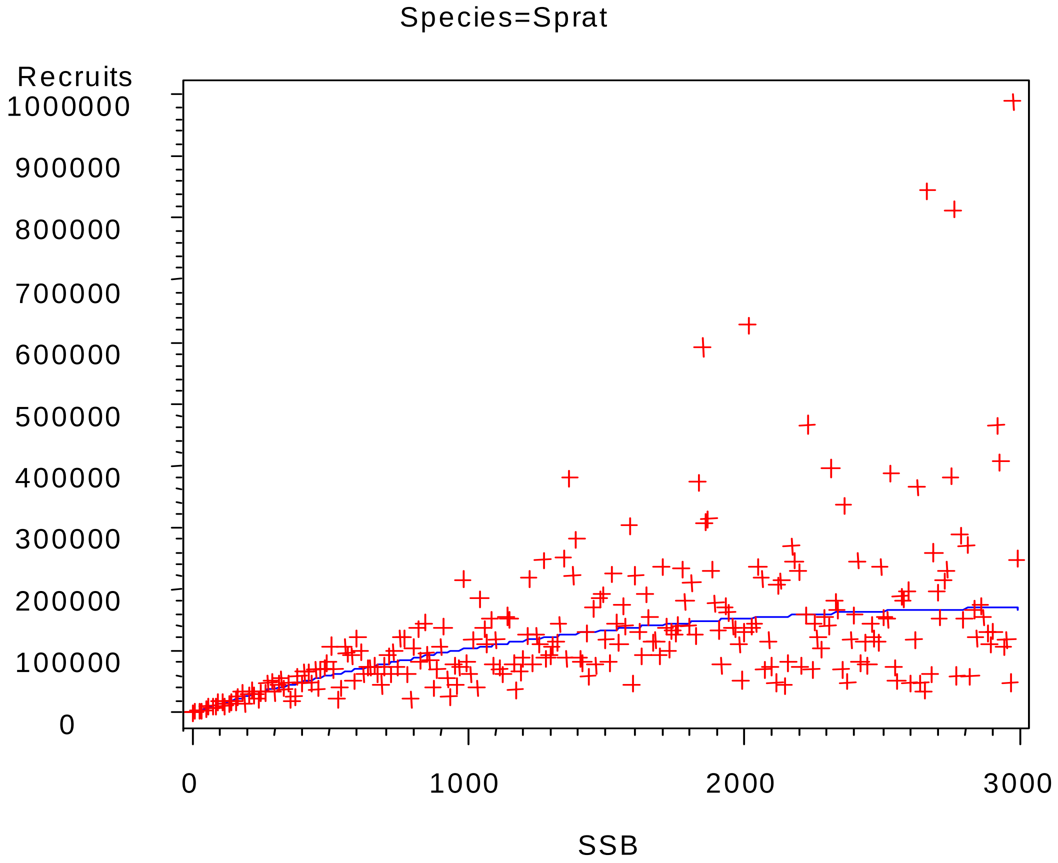


Figure 4.2.2 Distribution of Ricker a and b parameters in Markov chain Monte Carlo trial for Central Baltic cod data.

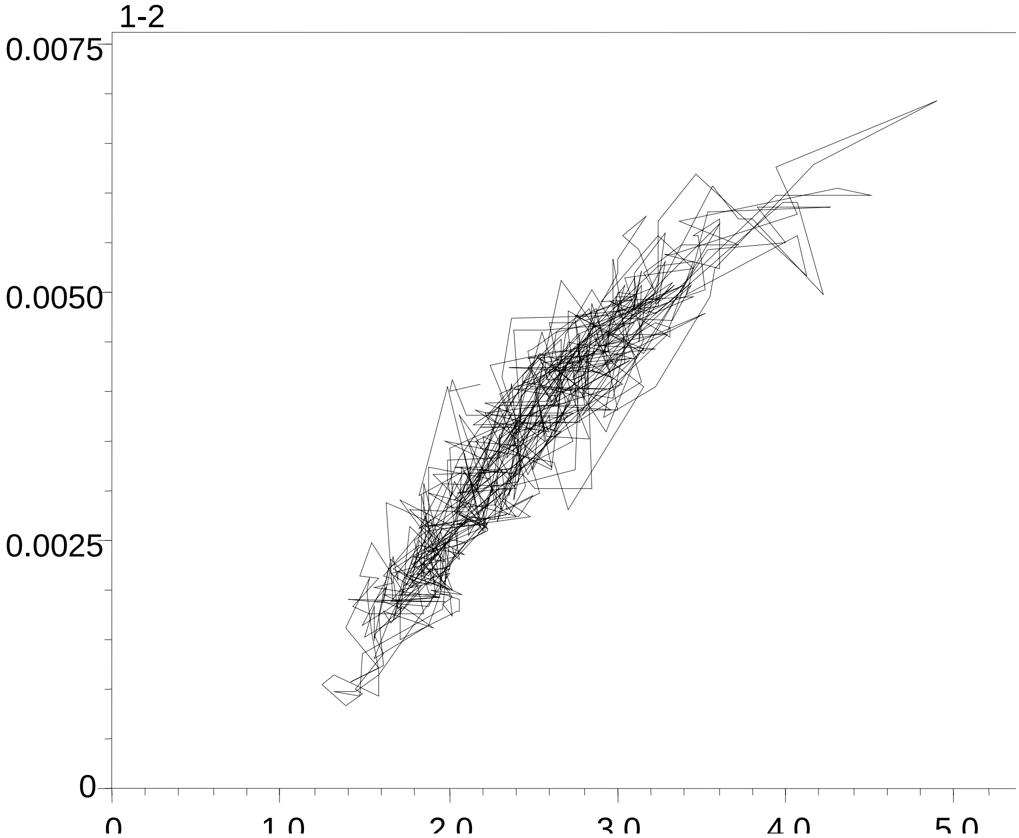
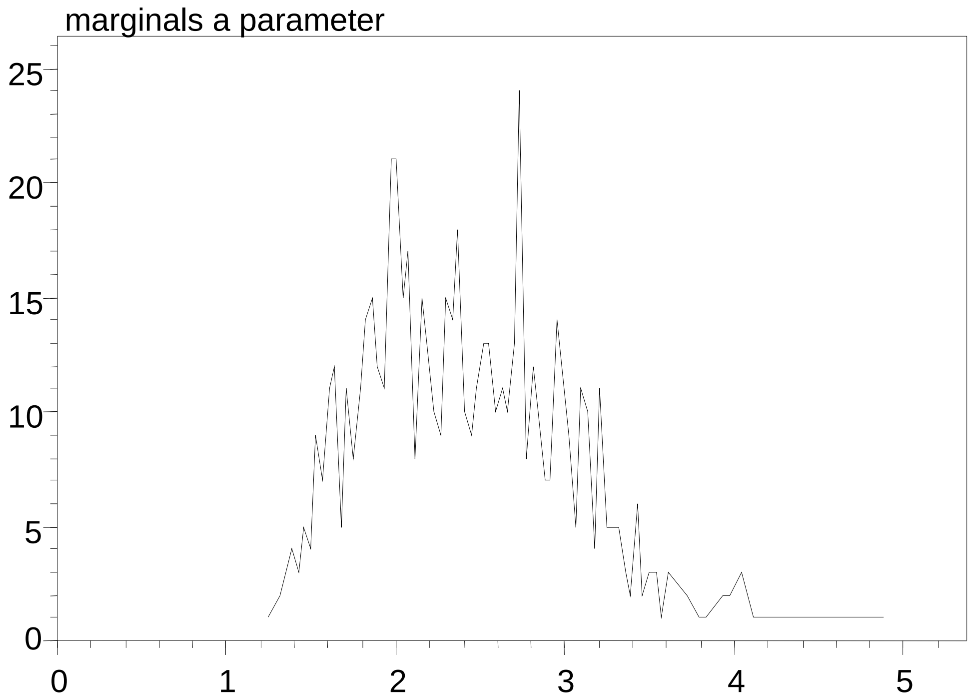


Figure 4.2.3 Ricker parameter frequency distributions from MCMC.



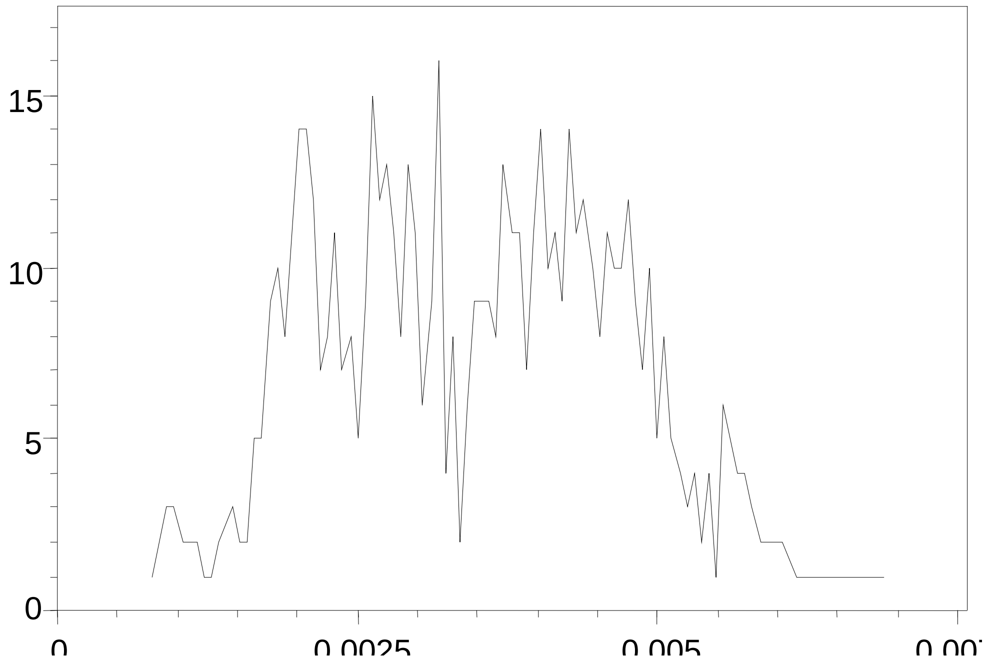


Figure 4.2.4 Likelihood plots for a and b parameters. The minima are the best estimates of the respecive parameters.

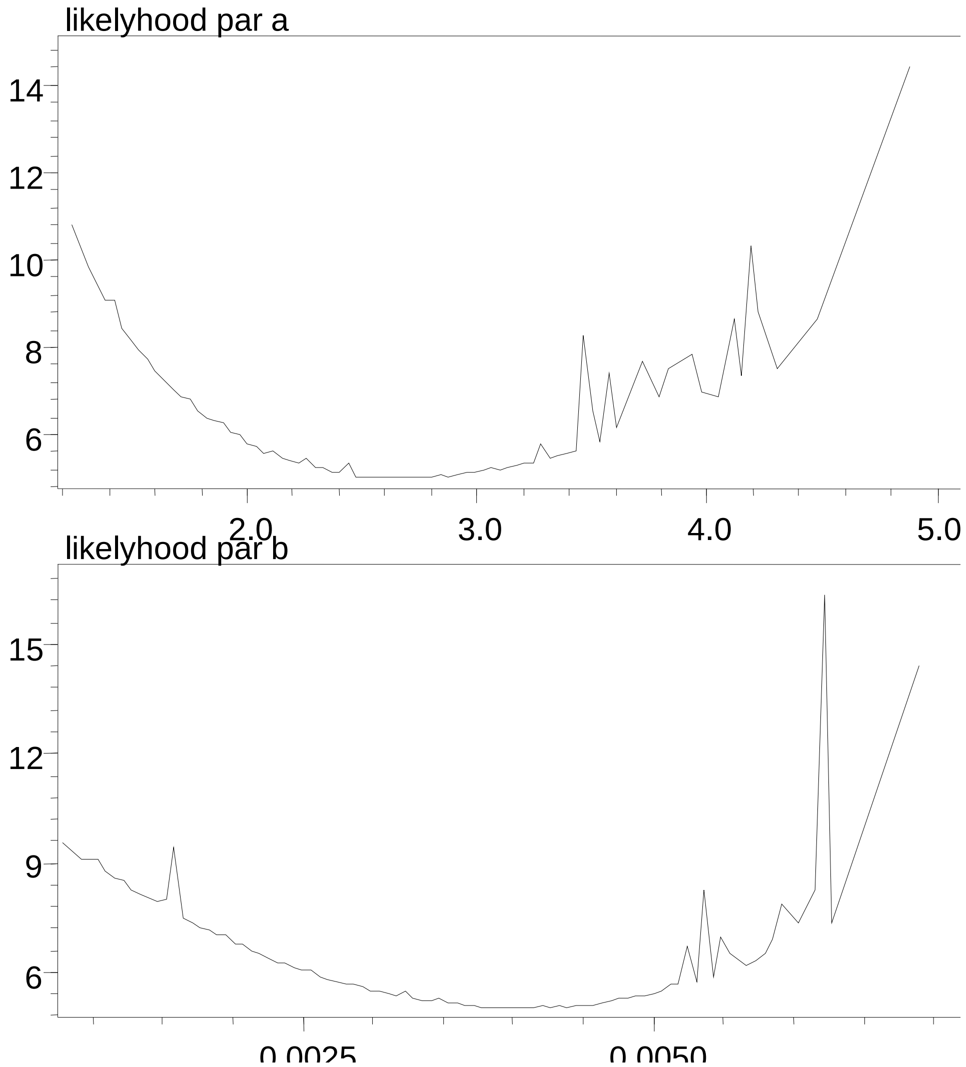
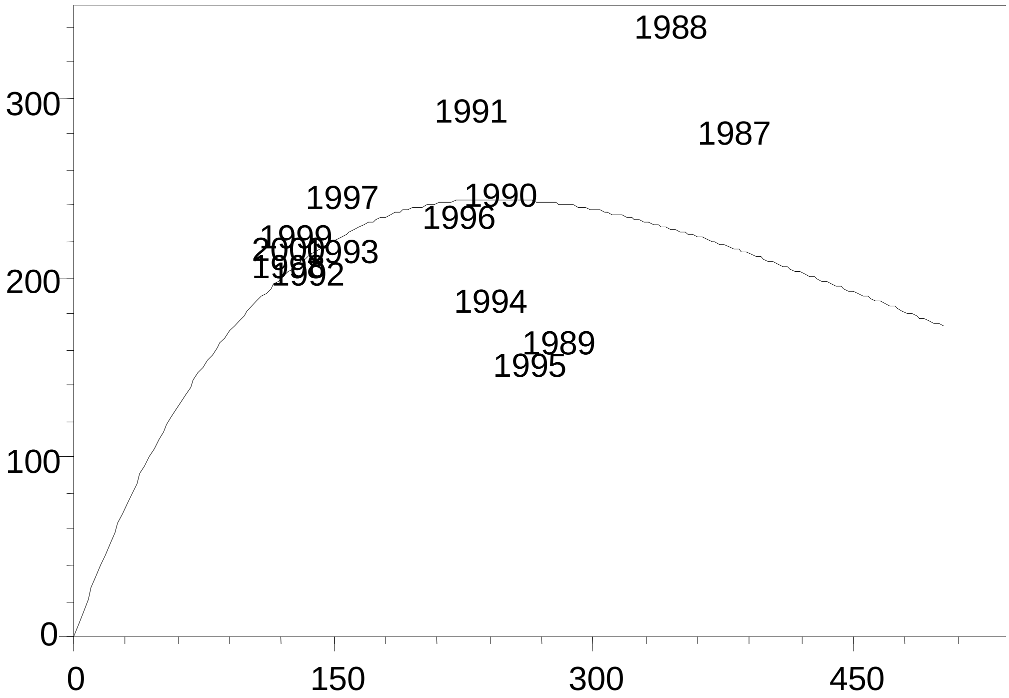


Figure 4.2.5 Fit to the original data of the best paramter estimates (upper plot) and 200 random draws from MCMC parameter set (lower plot).



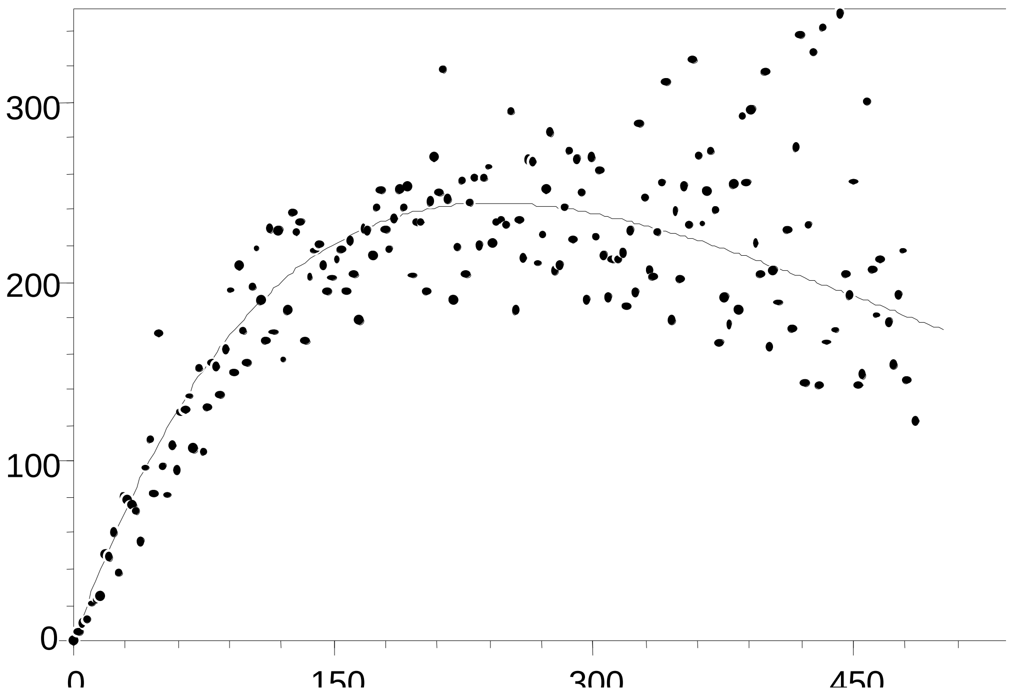


Figure 4.2.6 “key-run” prediction.

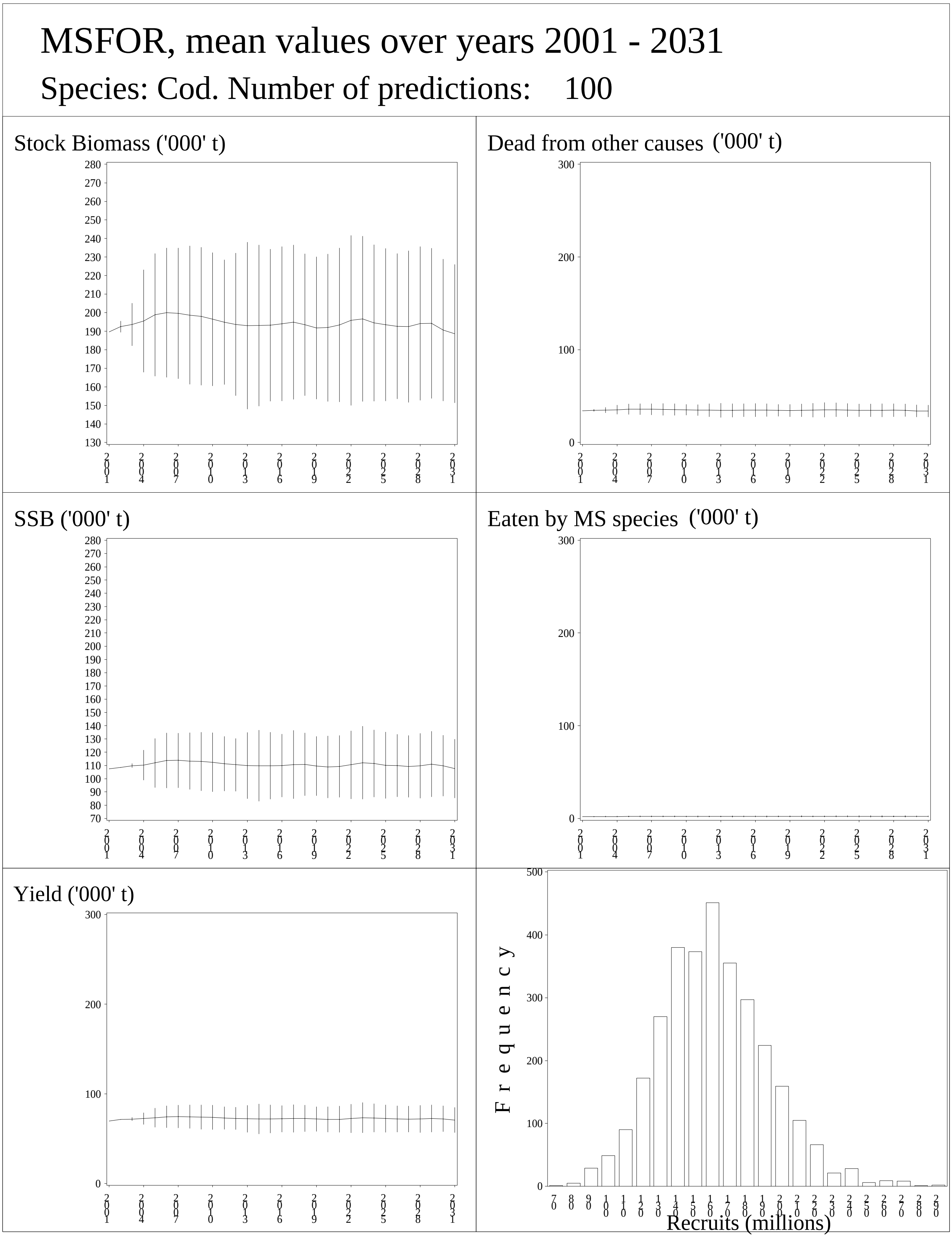


Figure 4.2.6 (continued). “key-run” prediction.

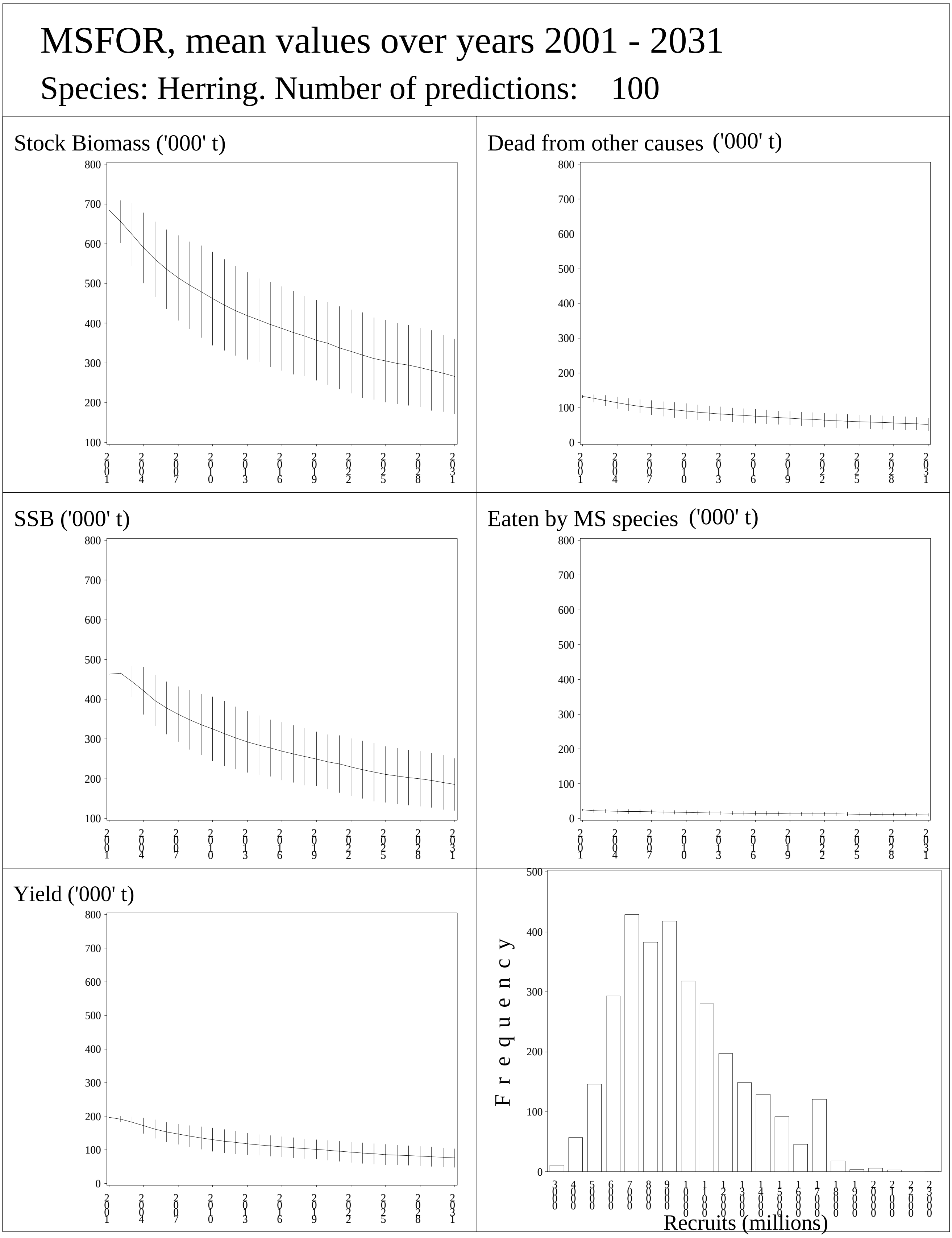


Figure 4.2.6 (continued). “key-run” prediction.

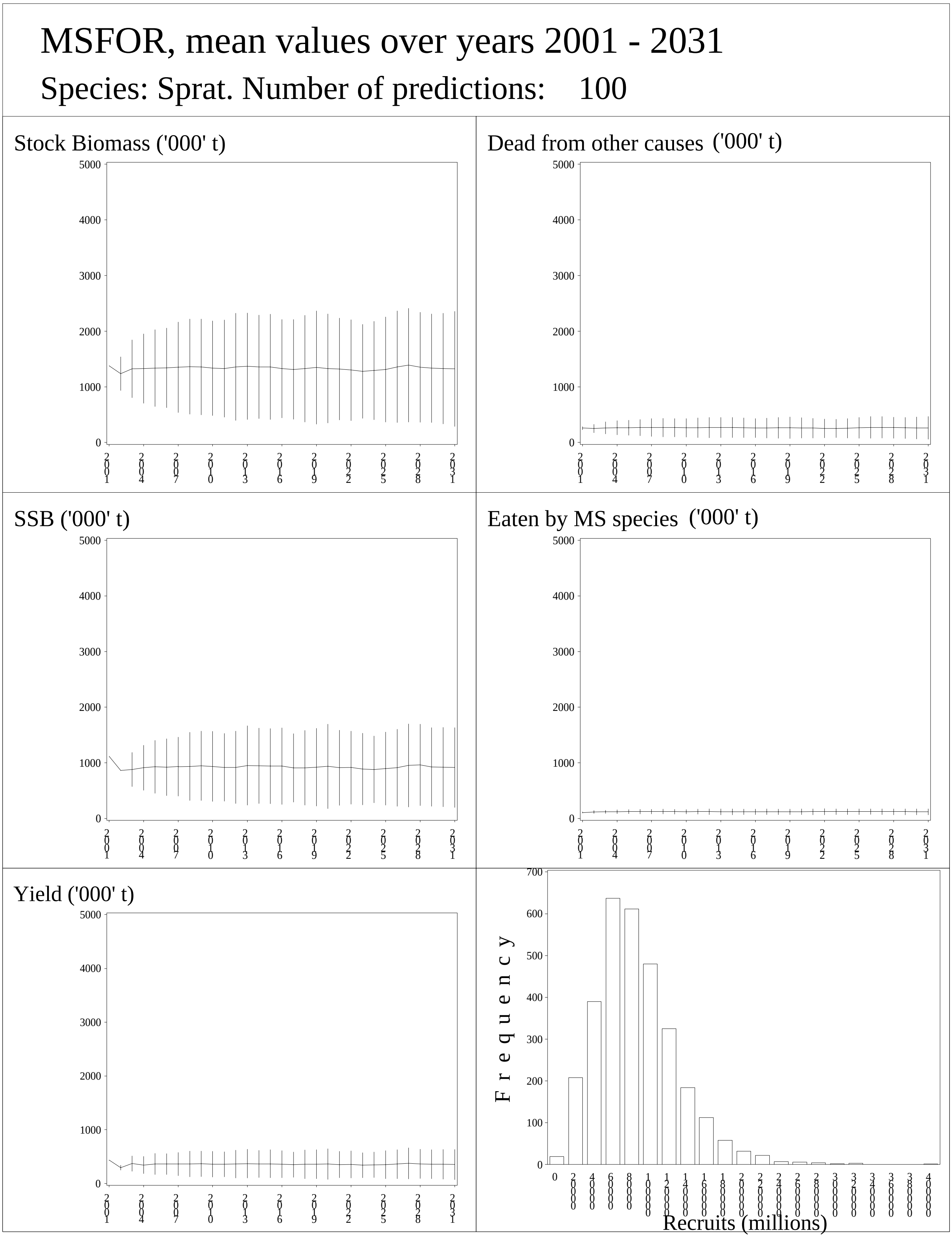


Figure 4.2.7 Fpa prediction.

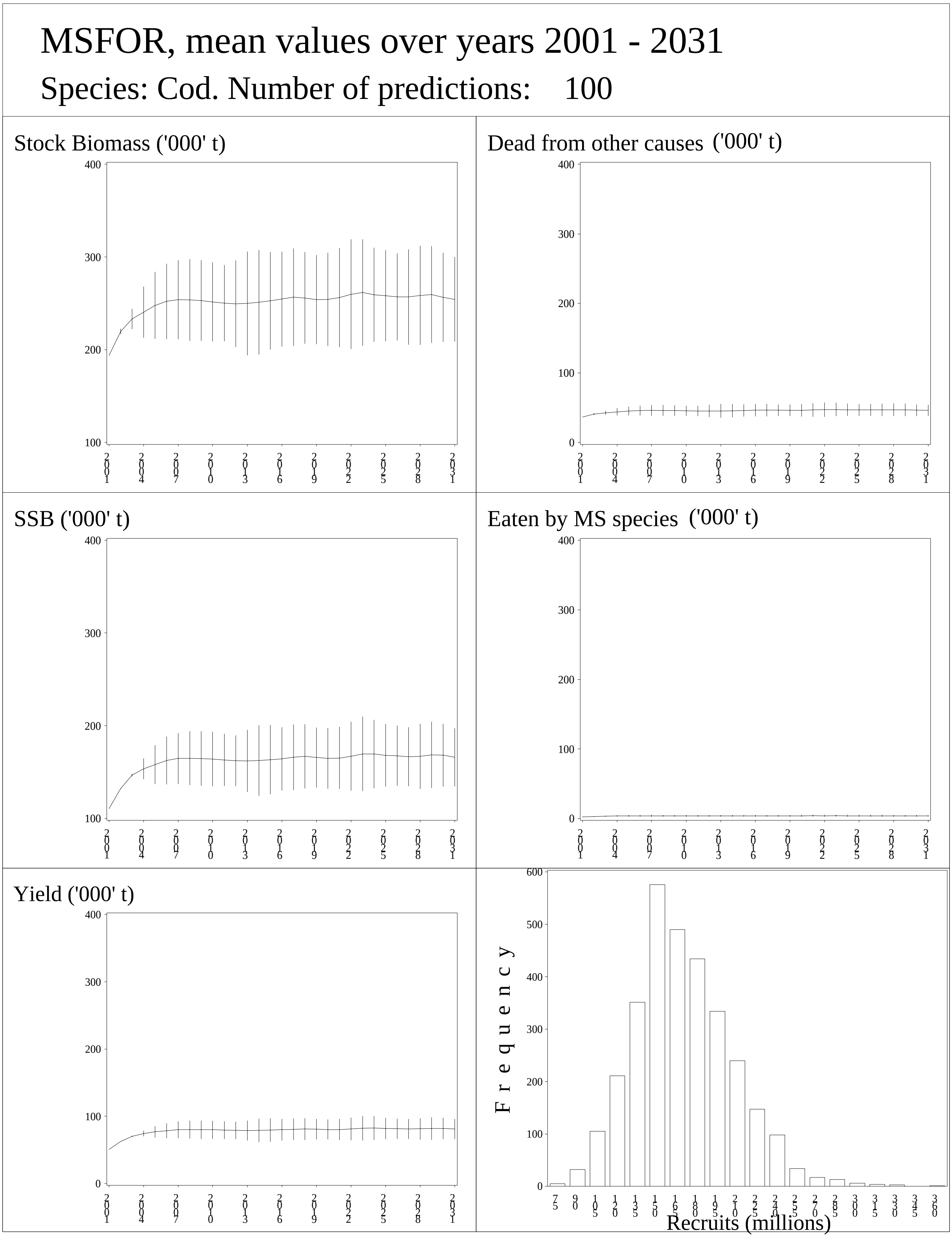


Figure 4.2.7 (continued). Fpa prediction.

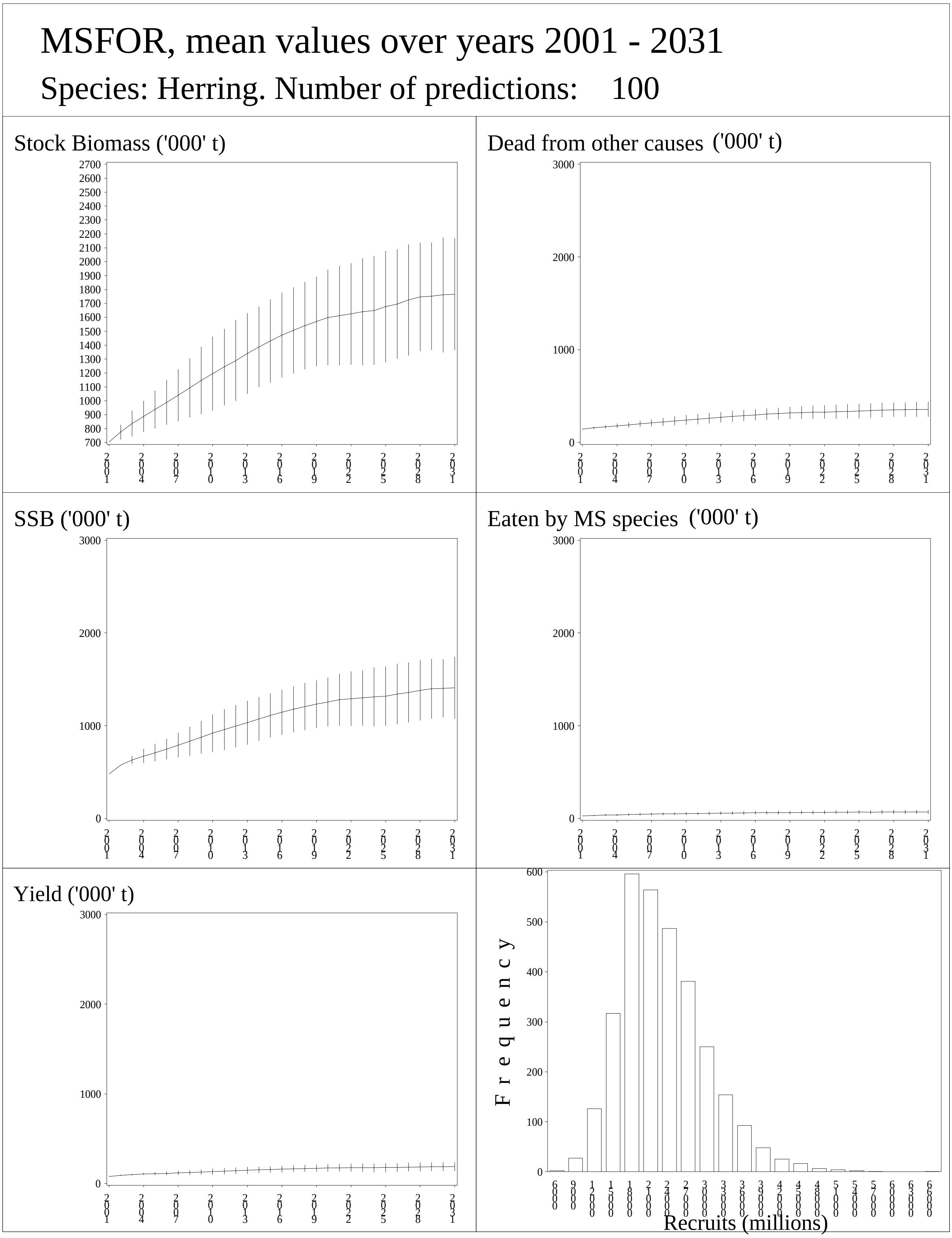


Figure 4.2.7 (continued). Fpa prediction.

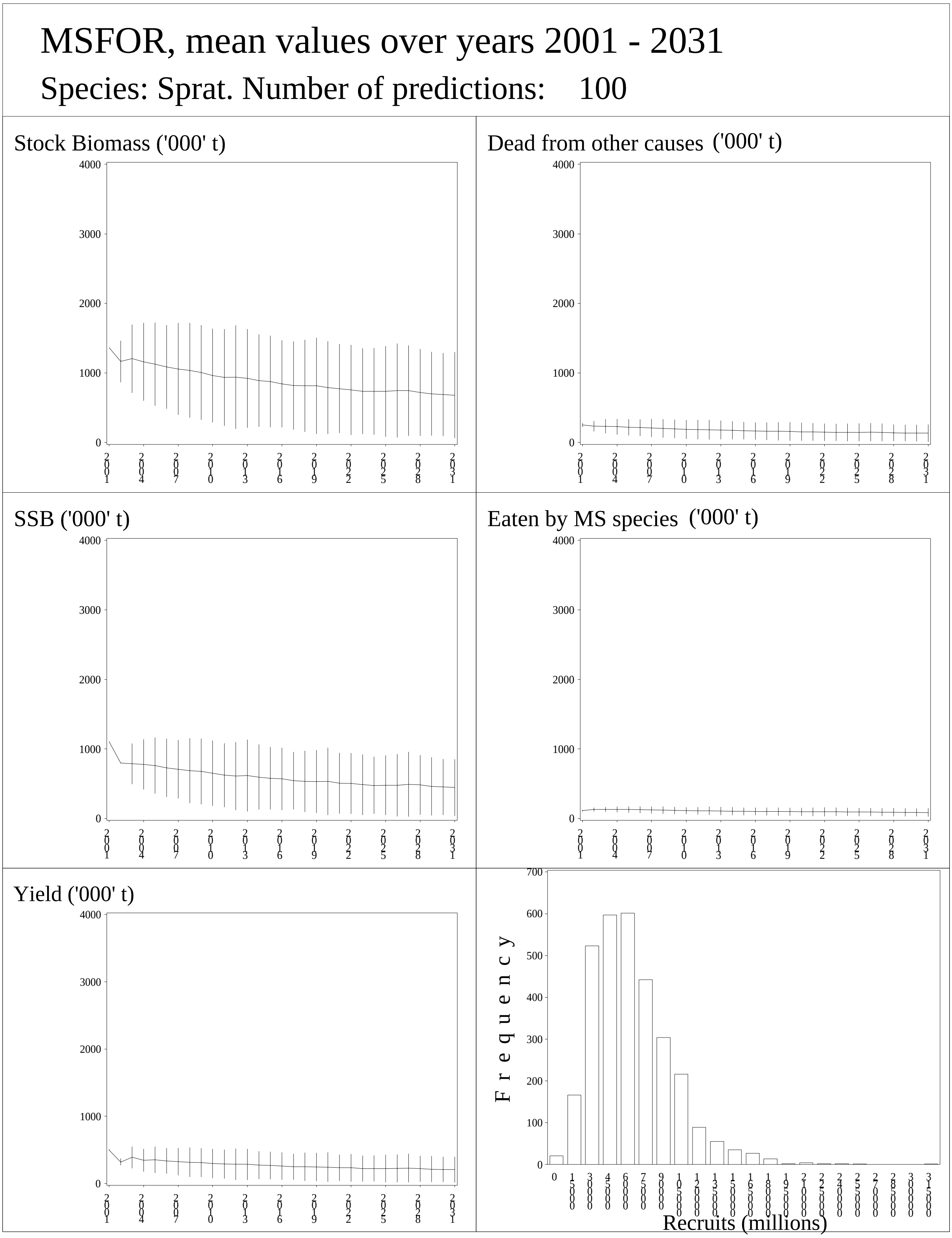


Figure 4.2.8 “High cod stock”prediction.

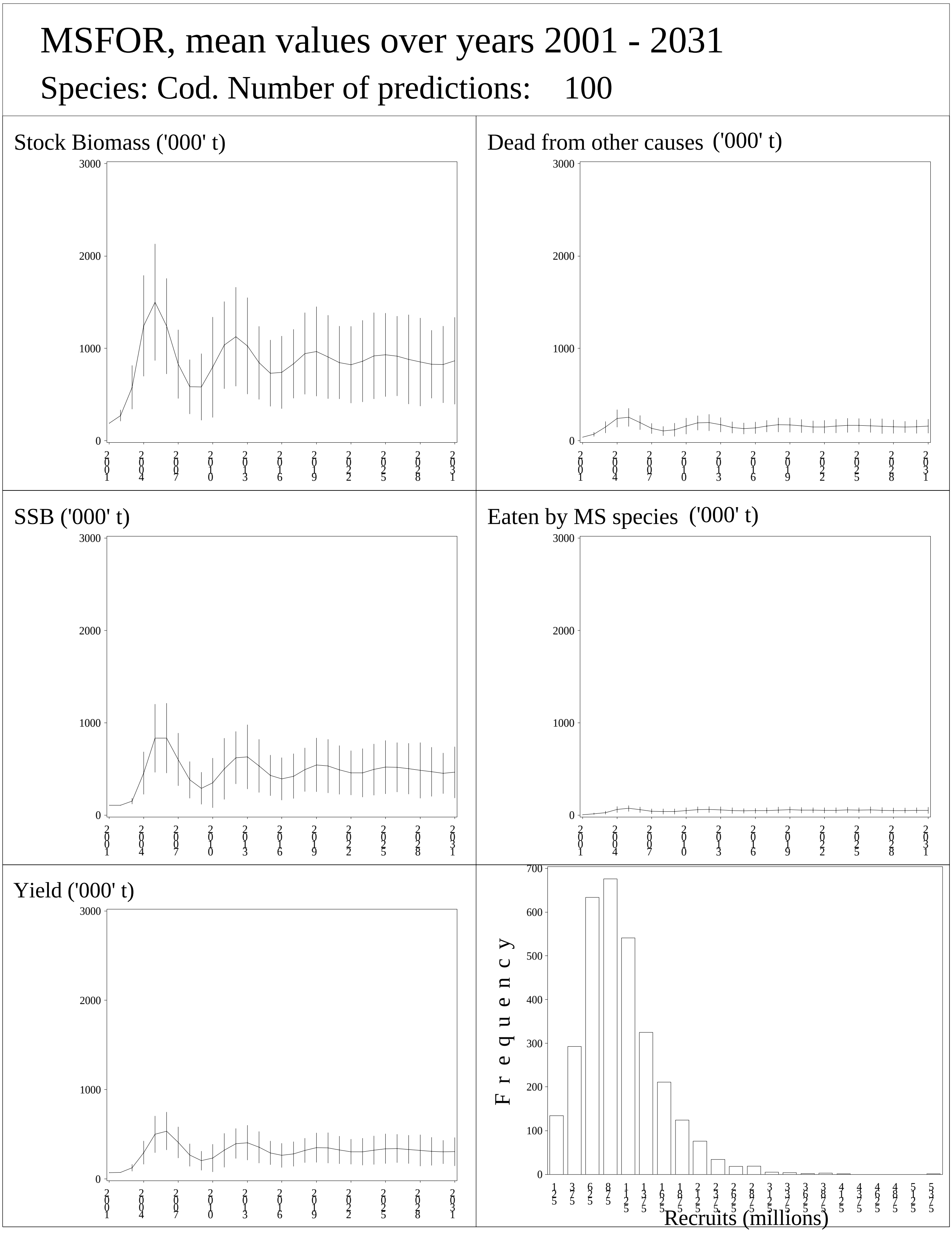


Figure 4.2.8 (continued). “High cod stock” prediction.

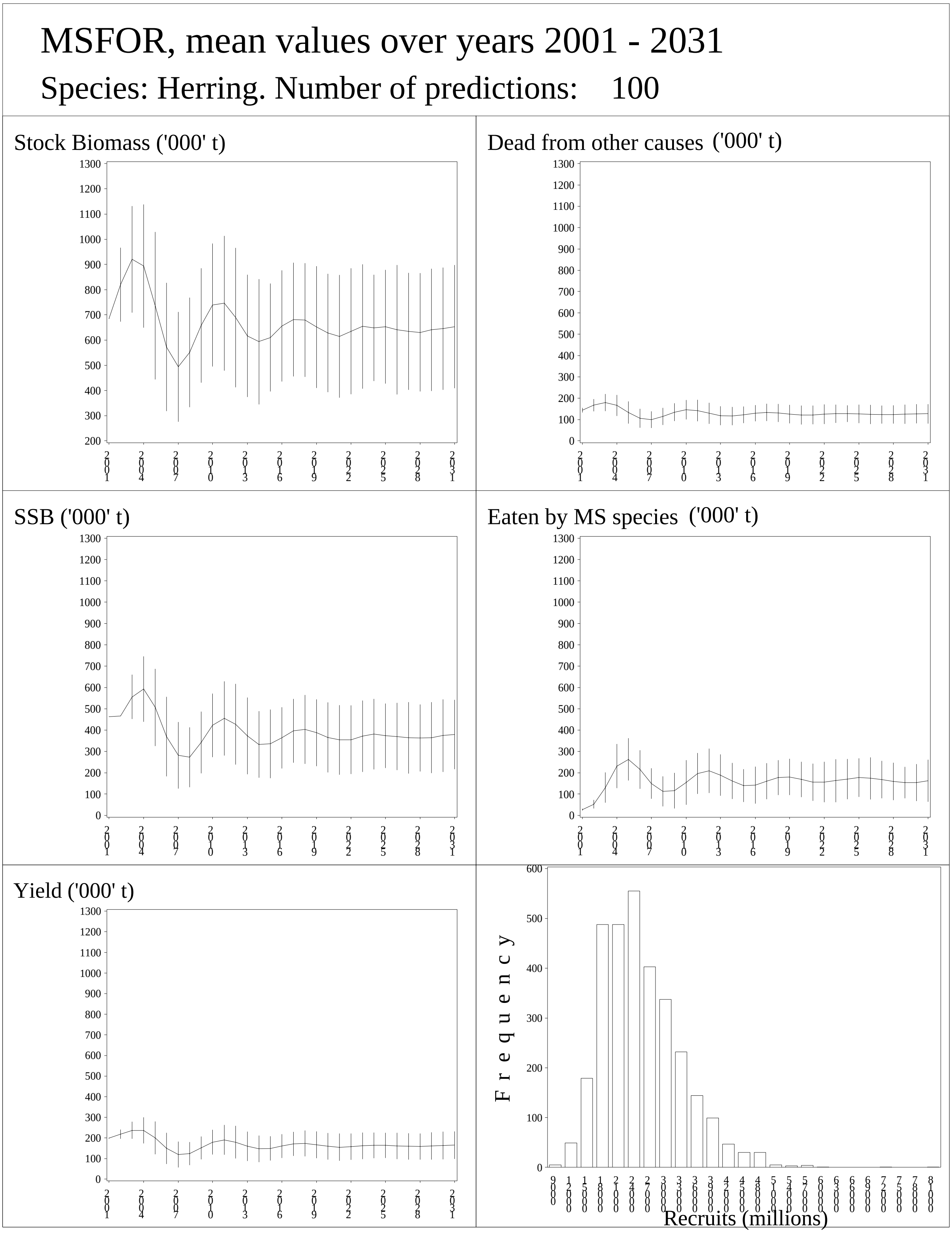


Figure 4.2.8 (continued).“High cod stock” prediction.

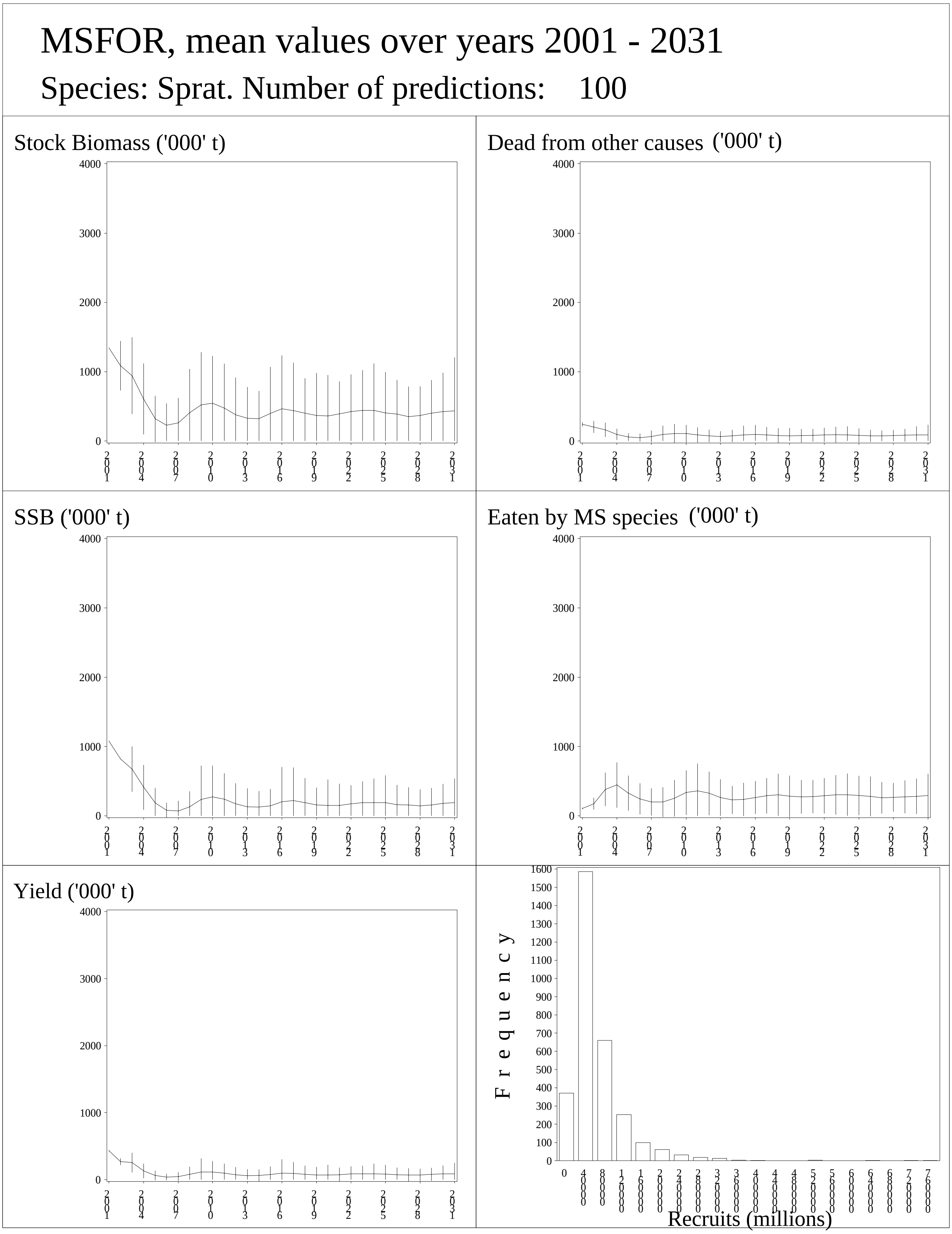


Figure 4.2.9 “Low cod stock” prediction.

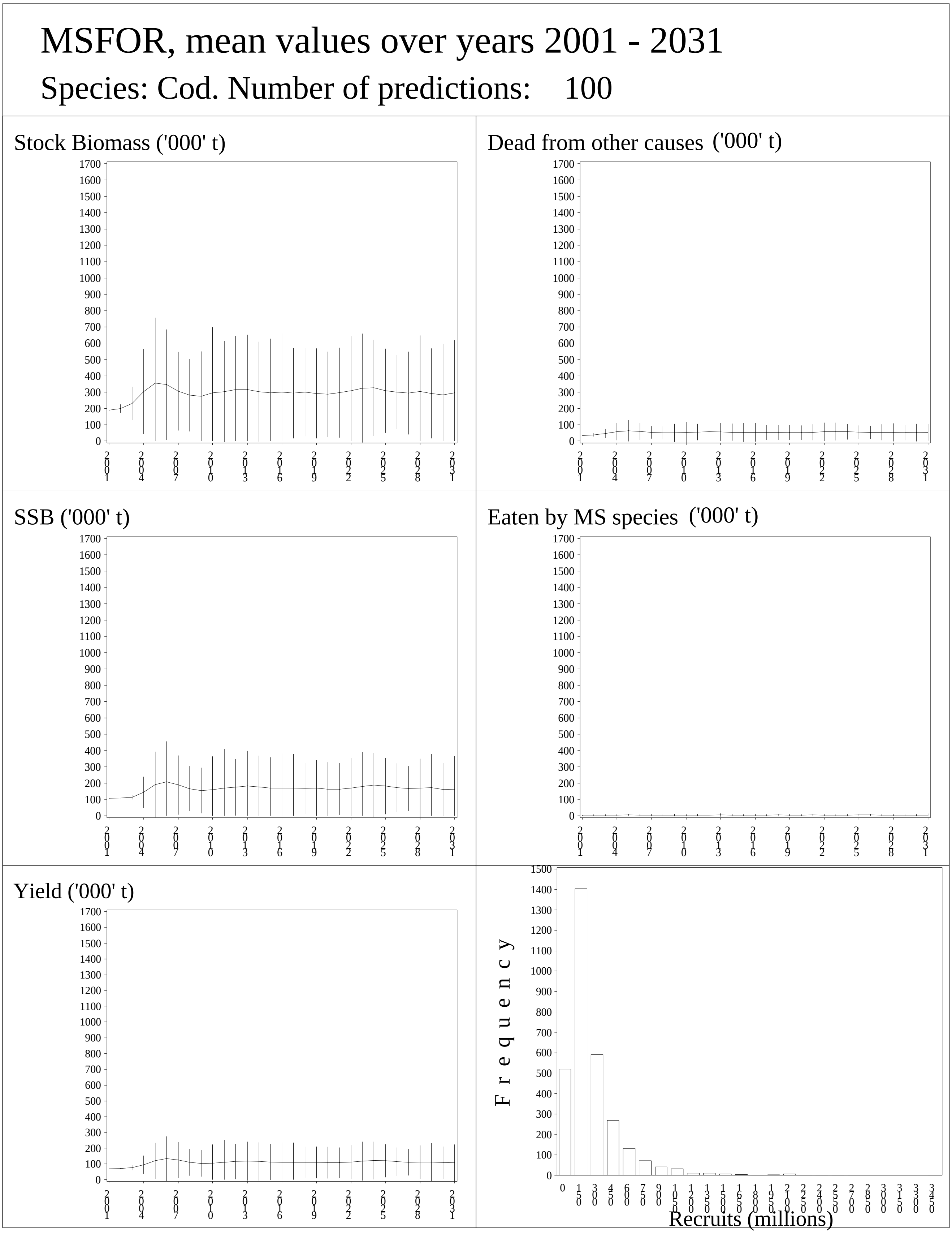


Figure 4.2.9 (continued).“Low cod stock” prediction.

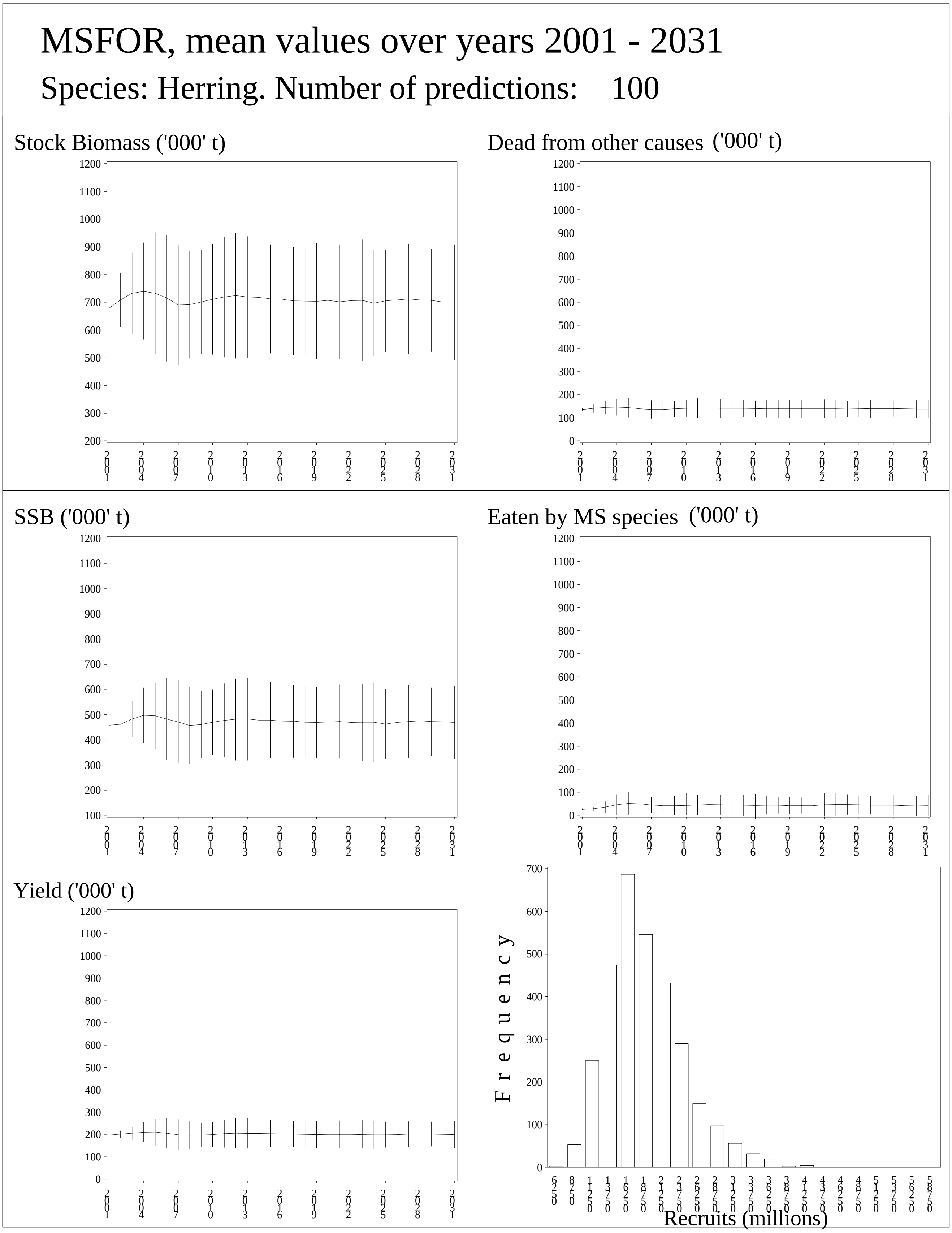
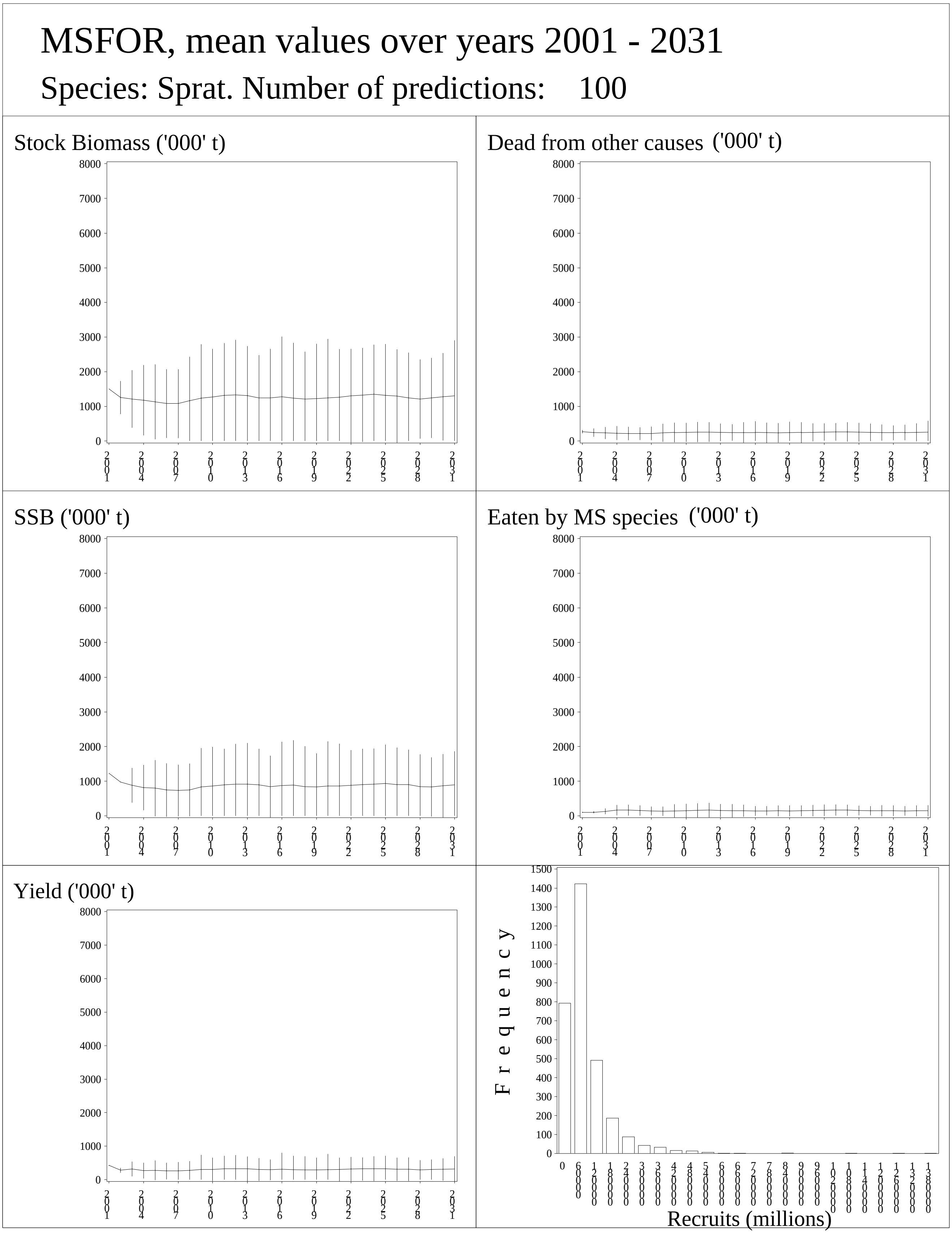


Figure 4.2.9 (continued). “Low cod stock” prediction.



5 REVIEW OF ENVIRONMENTAL PROCESSES AFFECTING POPULATION DYNAMICS OF COD AND SPRAT

As basis of constructing environmentally based short-term prediction and medium- to long-term projection models, a review of information on environmental processes affecting the population dynamics of cod and sprat has been conducted. For herring, a similar exercise is planned to be carried out inter-sessionally incorporating specific expertise on herring stocks in the Baltic not available in the present Study Group. In a first attempt to structure and rank the compiled information Section 5.3 contains a table indicating the relevance of major processes for predictions on different time scales under different environmental scenarios and a table giving sources of information and necessary actions to include important variables and parameters in multispecies predictions.

5.1 Overview

The Baltic Sea is considered a relatively simple ecosystem, and due to its restricted species diversity and trophic structure it may be easier to understand and model. Hydrographically the Baltic Sea is unique and resembles an estuary. Vertically, it represents intensively stratified estuarine system resulting due to the interaction of river runoff and the inflow of saline water from the North Sea and Kattegat.

In the Baltic a seasonal thermocline develops in spring due to surface heating and is maintained due to solar inputs until the autumn. Between the summer thermocline and the halocline exists a cold intermediate layer termed the winter water. The summer thermocline deepens in the autumn due to the combined effects of heat loss due to surface cooling and wind induced entrainment eventually coalescing with the remnants of the previous winters cold intermediate water. This results in a relatively homogenous surface mixed layer down to the permanent halocline, which has developed as a result of intrusions of saline North Sea water into the basins. Horizontally circulation patterns are determined by wind stress with no persistent hydrographic mixing features occurring during the summer months.

In the Baltic Sea the hydrographic complexity is low to medium depending on the area and mixing processes coincidental with regular autumn and spring mixing. The degree of trophic coupling is high because of short distance between trophic levels. The zooplankton community is complex, where both marine and freshwater organisms live side by side. The fish community in the open sea is considered simple and the exploitation rate of main fish species is rated from moderate to high depending on area of observation.

The Baltic Sea is dominated in upper trophic levels by three major fish species (cod, herring and sprat). In this system coupling of recruitment success to hydrographic processes and ephemeral inflow events has been described relatively successful in some cases and for example a clear relationship between the recruitment success of cod and the oxygen levels in the deep basins has been shown.

Typically, there are two different assumptions in modelling the structure and function of marine ecosystems. The first is based on the assumption that resource limitation or “bottom-up” factors are the dominant variables structuring ecosystems and the second one is based on the effect of predation or “top-down” processes within adjacent trophic levels. In the Baltic both strategies seem to be relevant.

The dominant mechanism controlling the ecosystem structure varies and is dependent upon the scales and time of observations. On large spatio-temporal scales, such as seasonal phytoplankton cycles bottom-up processes dominate, while on smaller scales, e.g., fish and zooplankton population dynamics may be dominated by predation.

The main questions considered in this section are:

- What are the main environmental and biological processes influencing population parameters to fluctuate
- What are the possibilities to incorporate various processes into the short term (2–3 years), medium term (5–10 years and long term (10–30 years) forecasts

After answering these questions the corollary simply is that what are the likely gains of incorporating environmental factors and biological processes into the models and under which circumstances are the gains likely to be highest i.e., in what circumstances the model have more explanatory power.

The following paragraphs give some conceptual models and ideas in more detail and listing of those processes, which have been documented in literature so far. The list is far from complete, but it tries to summarize main processes, without any ranking, to be taken into account, when constructing statistically solid models. This material is mainly extracted from the results of European Union funded concerted action SAP (Sustainable Fisheries) report, which is under preparation.

5.2 Detailed Background Information on Relevant Bio/Physical Processes

The following section contains an extensive literature review on various environmental processes affecting the stock dynamics of cod and sprat, being potentially important for conducting multispecies stock and catch predictions in the Baltic. This compilation is mainly based on review activity conducted within the EU-project SAP (2001). Table 5.2.1 briefly summarizes predictor variables and functional relationships of the most important processes identified, giving also related references.

5.2.1 Spatial distribution from research surveys

The present section summarises information on the fine-scale vertical (in the order of meters) and meso-scale horizontal distribution (in the order of few to 100 km's) of both species. The planktivore sprat is a major prey of the top-predator cod (e.g., Sparholt 1994), however sprat also preys on early life stages of cod (Köster and Möllmann 2000a), both processes depending on the fine- to meso-scale spatial and temporal predator/prey overlap. Both adult cod and sprat aggregate in the deep Baltic basins to spawn, having largely overlapping spawning times, but show different spawning behaviour and vertical distribution (e.g., Bagge *et al.* 1994, Parmanne *et al.* 1994). However, hydrographic conditions conducive for cod and sprat egg survival and food supply for larval and early juvenile stages may vary considerably not only between, but also within spawning areas (e.g., MacKenzie *et al.* 1996). Thus, the distribution of the spawning effort within and between spawning areas appears to be of importance for the reproductive success.

Fine to meso-scale vertical/horizontal distribution

The distribution of **cod** in the Baltic during spawning time is limited by low oxygen saturation in the deep water and in the mid water layer by the halocline (Tomkiewicz *et al.* 1998). The volume of the suitable habitat defined on basis of oxygen and salinity preferences varied between years and areas as well as the water quality within this habitat (Neuenfeldt and Tomkiewicz 2001). **Sprat** shows approximately the same oxygen preference and threshold levels as cod, however no salinity preference is detectable in the Central Baltic, which appears to be reasonable as sprat perform diurnal migrations into upper water layers from spring to autumn. The avoidance of upper surface layers during winter and intermediate water layers in spring appears be related to the temperature preference (Rechlin 1967), with the intermediate water above the halocline being significantly colder as water layers in or below the halocline. The gonadal maturation stage does not affect the distribution of sprat, i.e., sprat encountered outside the main Bornholm Basin had in May/June on average the same gonadal maturation stage than inside the basin (STORE 2001). In contrast, earlier observations showed that cod encountered outside the Bornholm Basin were less progressed in their gonadal maturation (Tomkiewicz *et al.* 1998).

Intra-annual variability in distribution and abundance within a Sub-division

CPUE values of **cod** from surveys covering the spawning area of the Bornholm Basin throughout the spawning season from April to August 1995–1999 revealed a clear picture of migration into the spawning area, with males concentrating earlier on the spawning grounds resulting in a high proportion of males during the early spawning period, which changes through spawning to a dominance of females (Tomkiewicz and Köster 1999). Larger males and even more pronounced larger females start spawning earlier and spawn over a longer period of time. For **sprat**, pelagic trawl surveys carried out in April, May/June and July 1988–1993 in the Bornholm Basin revealed a significant reduction in catch rates in July, indicating that sprat leave the spawning area after finalization of spawning activity (Köster 1994). This is confirmed by relative distributions derived from hydroacoustic surveys conducted in May/June in comparison to July/August throughout the 1980s (Falk *et al.*, 1981; Kästner and Krenkel 1981 and 1983, Kästner *et al.* 1984; Orlowski, 1985, 1988, 1989a, 1989b; Shvetsov *et al.*, 1986). Hydroacoustic survey results obtained in successive autumn and spring surveys in 1998/1999 (ICES 1999a, STORE 2001, ICES 2000) revealed a shift in distribution of sprat between seasons, with a relatively even distribution of sprat in open sea areas of Sub-division 25 and a concentration of sprat in the deeper basins in Sub-division 26 in spring, while in autumn, high concentrations were also found in shallower water areas mainly of Sub-division 26.

Intra-annual variability in distribution and abundance between Sub-divisions

A consistent increase in relative CPUE of **cod** from February to August 1996 in the Bornholm Basin with a concurrent decrease in relative CPUE in the Gdansk Deep and the Gotland Basin has been described by Tomkiewicz and Köster (1999). The authors interpreted this as migration of cod from the Gdansk Deep and the Gotland area to the Bornholm Basin for spawning, as hydrographic conditions are considerably more favourable for successful spawning here, a process which has been described earlier on basis of tagging experiments (e.g., Aro 1989) and commercial CPUE-values (Lablaika and Lishev 1961). With respect to changes in the distribution of juvenile cod, the seasonal development of age-group 2 catch rates in Latvian bottom trawl surveys conducted in Sub-division 28 at low levels of age-group 1 occurrence in the preceding year, suggests a migration of these juveniles from southern nursery areas in Sub-division 26 into the Gotland Basin (Plikshs 1996). This has been confirmed by a comparative analysis of the distribution of age-group 1 and 2 as obtained by the international bottom trawl survey (STORE 2001). For **sprat** a re-distributions between Sub-division has been described by hydroacoustic surveys in Sub-division 26 and 28 carried out in May/June and September/October 1994 and 1995 (Vasilieva 1996). This re-distribution has been explained by unfavourable overwintering conditions in the Gdansk Deep resulting in a movement out of the area. The overwintering volume in the Gdansk Deep, i.e., the water layer ensuring temperatures >3–4°C and oxygen concentrations > 1–1.5 ml/l was in 1994 only 10–20 m thick. As sprat densities were additionally high, a large proportion of the population obviously left the area (Vasilieva 1996).

Inter-annual variability in distribution and abundance within Sub-divisions

Based on the resolved oxygen and salinity preference and thresholds levels of **cod**, habitat volumes and habitat areas with water conditions >20% oxygen saturation and >11 PSU have been determined (STORE 2001). Habitat areas of cod show pronounced deviations between post-inflow and stagnation periods in all areas of the Central Baltic, meaning that independent of stock size, densities and most likely also commercial and research catchabilities will change. As specific areas within a Sub-division have a higher likelihood to sustain suitable habitat conditions, it is most likely that the distribution of cod will change accordingly. In principal, habitat volumes of **sprat** can also be determined, however, in seasons when diurnal migrations are performed, this exercise will be difficult. An obvious application is to determine the overwintering volume of sprat.

Inter-annual variability in distribution and abundance between Sub-divisions

Catch rates from the Baltic international trawl survey revealed substantial changes of the **cod** abundance and distribution with time, i.e., a depletion of the spawning stock in the eastern Baltic basins with intermediate signs of recovery in Sub-division 26, but not in Sub-division 28 (Sparholt and Tomkiewicz 2000, Aro 2000). The distribution of recruits at age 1 shows maximum densities in the southern Sub-division 26, an area not sustaining regular egg development at least since the mid of the 1980s. In contrast, in Sub-division 25 the hydrographic conditions did allow a regular reproduction and the major part of the remaining spawning stock concentrated in the Bornholm Basin resulting also in relatively high egg productions (Köster *et al.* 1999). Drift model simulations confirmed that a drift of larvae and pelagic juveniles is responsible for the high abundance of 1 year old cod in the neighbouring Sub-division 26 (Aro *et al.* 2001). This drift pattern explains also the deviations between trawl survey and MSVPA based distributions (Köster *et al.* 2001). Further noteworthy is the re-distribution of age-group 2 year old recruits, which migrate out of Sub-division 26 south into northern and probably also western direction, confirming a preliminary analysis of catch rates from surveys conducted at different times of the year in the Gotland Basin (Plikshs 1996).

The relative distribution of the adult **sprat** stock according to Sub-division as derived from the international hydroacoustic survey in autumn shows significant time trends with first increasing and then declining importance of Sub-division 24 and 25 during the 1980s (STORE 2001). The relative abundance in Sub-division 26 was stable until mid 1980s, but decreased to values well below 20% in most recent years as well. Relative abundance in Sub-division 27 increased to historic high values in most recent years, while the corresponding values in Sub-division 28 and also 29 south were already relatively high since 1989. The distribution of recruits is different, with highest abundances of age-group 1 in general occurring in Sub-division 26 independent of the spawning stock size in that area. In contrast, recruits are seldom encountered in high quantities in Sub-division 25, while their occurrence in Sub-division 28 is very variable. Areas neighbouring Sub-divisions containing main spawning areas, i.e., Sub-division 24, 27 and 29 south showed in general relatively low recruitment. Reason for the determined long-term shifts in relative abundance of sprat may be i) spatially heterogeneous distribution of fishing effort and predation of cod both acting more intensively in southern stock areas, ii) density dependent migrations out of the central stock distribution area at high stock sizes, this might occur especially from Sub-division 28 to 27 and 29, iii) hydrographic factors affecting the distribution, i.e., cold winters resulting in dense overwintering aggregations in the deep basins with a pronounced halocline ensuring temperatures well above those in the mixed surface layer.

5.2.2 Maturation and weight at age

Maturity ogives, sex ratios and mean weights

An analysis of **cod** maturity ogives based on the data from the International Baltic trawls Survey (BITS) showed that males generally mature at a younger age than females, and that the age at which sexual maturation occurs, increases with distance from Kattegat and the Danish Straits independent of sex (Tomkiewicz *et al.*, 1997). This pattern, however, coincides with documented discrepancies in otolith age determination between ‘western’ and ‘eastern’ age reading laboratories in the Baltic with otoliths given older age towards the East (ICES 1999b). While setting up a length based database not affected by age-reading problems, further exploratory analysis of the age based data-sets showed, that the large deviation between proportions of females being sexually mature at an age of three between different areas cannot be explained by age-reading problems alone (STORE 2001). Variability in weight at age in national data sets unaffected by age-reading problems, revealed a clear difference in sexes, with females having higher weight. Higher weight at age in both sexes encountered in the early 1990s coincide with a period of very low stock size, especially in eastern Baltic areas, which showed also most contrast in the weight at age data. Comparing weight at age combined for both sexes between different Sub-divisions within specific periods, revealed in general highest mean weights in intermediate age-groups (4–6) in Sub-division 28, while lowest values were derived for Sub-division 25. In addition a considerable difference between immature and mature fish in size at age was detected. The appearance of differences in weight at between sexes in mature and not in immature fish indicates that maturation affects growth, which is in fact also suggested from the higher increase in length with age of immature compared to mature fish (STORE 2001). Weight at age 3–5 in the catch show a significant increase throughout the 1980s in all Sub-divisions (ICES 1997b), while weight at age in the stock from trawl surveys compiled since 1993 showed a decrease in weight at age in most recent years (ICES 2001). An analysis of the weight at age in the catch database revealed the main contributors to explain observed changes as i) the total cod stock biomass, ii) the total biomass of sprat and iii) the total biomass of all cod prey species in the area. In Sub-division 28, the ambient oxygen content in cod feeding grounds and feeding habitat seems to be a significant factor for mean weight at age as well (Aro *et al.* 2000).

Variations in reproductive ecology of Baltic **sprat** such as sex ratios, maturity ogives, timing of spawning and fecundity have not been considered in regular stock assessment (ICES 2000). Improved knowledge about the sex and size specific gonadal maturation process, the timing and duration of the spawning season as well as the spawning frequency in combination with fecundity appears to be important for the understanding of recruitment success. Analysis of historic and newly available data on sexual maturity at age collected during the STORE project has been undertaken in close cooperation with the ICES Study Group on Baltic Herring and Sprat Maturation. The data covering the period 1976–1999, with some years in the late 1980s missing, indicated significant variability of proportions of age-group 1 sprat being mature and showed a clearly skewed sex ratio with a dominance of female with increasing age (STORE 2001).

Baltic herring weight at age declined by more than 50% in all age-groups since the beginning of the 1980s (Raid and Lankov, 1995, Cardinale and Arrhenius, 2000). A similar decrease has been observed for Baltic sprat, only starting later. For herring, three different hypotheses have been put forward for explanation. First of all a decrease in size specific predation of herring by cod is apparent (Beyer and Lassen, 1994), as smallest herring of an age-group are considerably more vulnerable to predation by cod than larger ones. Secondly, as the herring assessment unit in the Baltic consists of a considerable number of sub-stocks with different growth rates (e.g., Ojaveer, 1989), a shift in dominance of these different sub-stocks has been suggested (Sparholt, 1994). Thirdly, a shortage of food supply, accelerated by increasing competition with the rapidly increasing sprat stock was hypothesized (Cardinale and Arrhenius, 2000). For sprat the explanation is easier than for herring, as the decline in weight at age started at a low predator abundance and additionally size selective predation is most likely of limited importance given the small variation in size at age for sprat age-groups 2+. Furthermore, there exist no such clearly distinct sub-stocks of sprat in the Baltic and those, which could be, separated (Ojaveer, 1989) show relatively similar growth changes as obvious from area-specific data compiled by ICES (1999b). With respect to the third hypothesis, weight at age is significantly correlated to the food availability per sprat (Möllmann, 2001) and daily rations estimated on basis of stomach content data and ambient temperatures applying a general model of gastric evacuation (Möllmann and Köster, 1999). Based on this exploratory analysis, it may be justified to use a relationship between weight at age and stock size for prediction purposes. Results of Cardinale and Arrhenius (2000) indicate that a similar relationship may be constructed for herring including sprat as a competitor.

Timing of spawning

If there is an association between the stock structure and the time and duration of spawning this might represent important sources of variability in the reproductive success of the stock due to seasonal changes in environmental parameters. Results of Hutchings and Myers (1995) indicated that the observed increase in the proportional abundance of younger individuals was concomitant with a decline in the duration of the spawning time; reducing the probability that larval emergence will match peak abundance of zooplankton. In the Baltic Sea sprat and cod reproduce in the same areas, but with significant differences in recruitment success. In order to investigate the causes for the difference in reproductive success, knowledge about, e.g., the timing of spawning of different stock components and the spawning stock composition is a prerequisite. A first analysis indicated that the duration of the **cod** spawning period of the stock depends on its size and sex composition, whereas the timing of peak spawning does not (Tomkiewicz and Köster 1999). The earlier start and also longer duration of the male spawning period in combination with earlier sexual maturation suggest that male mortality exceeds that of the females due to increased natural mortality as well as prolonged exposure to fisheries activities (Berner 1985). A first comparative analysis of the timing, duration and spawning frequency of **sprat** in 1999 showed an extended spawning season lasting from early February to late July with a distinct peak in early June in 1999 and an average spawning frequency of 27% indicating a spawning interval of approximately four days (STORE 2001). A clear trend towards later spawning was observed from 1995 to 1999 in Sub-division 25. In comparison to southwestern Sub-divisions, the spawning season in northern stock areas was delayed in 1999.

5.2.3 Individual egg production and viability of sex products

Individual fecundity

Egg production models for **cod** in the Baltic are presently not used in stock assessment, partly because the necessary input data for key parameters (e.g., individual fecundity, maturity ogives) are not available either for a sufficient number of years, or are not available on an annual basis. Evidence from other cod and haddock stocks shows that variations in fecundity or, more simply, condition (e.g., Fulton’s K) can be responsible for significant amounts of variation in recruitment-spawner biomass relationships (Marshall *et al.* 1998; Marshall and Frank 1999). An extensive analyses of individual cod fecundity revealed that the relative fecundity is independent of body size. Relative fecundity varied between years, but neither between spawning areas in the Central Baltic nor between different months within one spawning season (Kraus *et al.* 2000). Inter-annual variations depend on water temperatures and especially the relative fecundity is influenced by growth rates in the months leading up to the next spawning period. A preliminary linear model using these variables to predict relative fecundity has been established (Kraus *et al.* 2000). Relative fecundity on an individual level was not related to fish condition at the time of capture.

In **sprat**, absolute batch fecundity is related to female size, while relative batch fecundity is not (Alekseeva *et al.* 1997). However, a significant intra- and inter-annual variability in relative batch fecundity was detected (STORE 2001). Relative batch fecundity increased from April to June within a spawning period and being significantly different in June of different years.

Viability of sex products in relation to age/size and condition

Egg quality, or the ability of a female to produce viable offspring, has been in focus lately in explaining stock recruitment relationships (Rijnsdorp *et al.* 1991; MacKenzie *et al.* 1996). Both changes in age composition and condition of spawners, and the relative abundance of a year-class have been put forward in explaining recruitment variability (Kjørsvik 1994; Solemdal *et al.* 1995; Marteinsdottir and Steinarsson 1998). This may be of particular importance for a declining stock due to heavy exploitation (e.g., Daan 1994; Schopka 1994) as for the Baltic cod. Hence, including maternal effects on variability in egg quality and estimation of the viable egg production may improve stock recruitment relationships. A number of investigations on different species, including cod, suggest that viability of eggs and larvae is positively related to egg size (e.g., Solemdal *et al.* 1995; Kjesbu *et al.* 1996; Marteinsdottir and Steinarsson 1998; Trippel *et al.* 1997), and that egg size vary according to female age/size and condition as well as spawning experience.

For Baltic **cod** a relationship between egg size and female size for Baltic cod was established (CORE 1998). Further, a positive relationship between egg size and larval size and survival during the yolk sac stage, as well as between egg size and egg buoyancy, was found (Nissling *et al.* 1998). This implies higher egg and larval survival for offspring originating from large eggs and thus a higher relative importance of older females for recruitment of Baltic cod (Vallin and Nissling 2000). However, no effect of female condition was obvious (STORE 2001). Potential paternal effects for the spawning success have been less studied. In the Baltic, marine teleosts have to cope with low saline brackish water influencing both fertilisation success and egg development (Solemdal 1970; Westin and Nissling 1991). Although Baltic cod is adapted to low saline conditions (Nissling and Westin 1997) fertilisation and thus spawning success may differ between both spawning areas and years, due to different hydrographic conditions. A minimum salinity of 11 psu is required for activation of spermatozoa and thus successful fertilisation (Westin and Nissling 1991). Variability of fertilisation capacity/success with salinity implies, that the viable egg production might vary with hydrographic conditions, e.g., between spawning areas. Further, fertilization capacity is lower early and late in the spawning period and it is related to male length and weight. This suggests, consistent with egg quality and female characteristics, that size/age of the fish affects viability of sex products and thus the spawning success.

Contamination of sex products by toxicants

During the period 1970–96, different types of reproduction disturbances, including inadequate ovary maturation, low fecundity and early life stage mortality, have been demonstrated for a number of fish species in the Baltic. Suggestions have been made that larval deformities and increased mortality in pelagic eggs of plaice, flounder and whiting and demersal eggs of herring are caused by chloro-organics like DDTs, PCBs, TCDD/F and other highly persistent bioaccumulative compounds (Westernhagen *et al.* 1981; 1988; 1989; Hansen *et al.* 1985). Recent studies on early life stages of fish (cod, herring, turbot and zebra fish) have shown that Critical Body Residues (CBR) for lipophilic narcotic chemicals were reached at 0.9–4.35 mmol/kg wet weight, respectively (Petersen 1997). However, if fish are already exposed to toxicants, only a low additional accumulation is likely to be needed before a toxic effect is expressed (van Wezel *et al.* 1996). In contrast to an investigation conducted in 1996 (Petersen *et al.* 1997), a new study did not reveal any correlation between **cod** larval hatching and survival rates and contaminant burdens measured nor with EROD or AChE activity in the ovaries (Schneider *et al.* 2000).

5.2.4 Population egg production

Spawning stock biomass as a measure of egg production

It has recently been questioned that standard stock assessment procedures provide estimates of spawning stock biomass, which can be used as a reliable measure of egg production (Marshall *et al.* 1998; Marteinsdottir and Thorarinsson 1998; MacKenzie *et al.* 1998). The present section presents results from corresponding tests for Baltic cod and sprat. According to the availability of time-series data, an exploratory analysis for cod was carried for Sub-division 25, comprising the Bornholm Basin (Köster *et al.* 2000). For sprat the exploratory analysis was restricted to the more eastern spawning areas in Sub-division 26 (Gdansk Deep) and Sub-division 28 (Gotland Basin).

The area-specific potential egg production of cod was estimated on basis of female SSB (Köster *et al.* 2001), coupled with predicted relative individual fecundity values (Kraus *et al.* 2000). For sprat, available information on maturity ogives, batch fecundity and spawning frequency (Petrowa 1960; Polivaiko 1980; Alekseeva *et al.* 1997) hardly allows to construct a reliable time series of potential egg production values. Thus, a proxy for the nutritional condition and the reproductive potential of the population was obtained from the anomaly in average growth rates from the 3rd quarter to the 2nd quarter of the year of spawning. Mean annual values for egg abundance are available for the different Sub-divisions from ichthyoplankton surveys carried out at peak spawning time 1976–1996. For cod, the data have been summarized by Köster *et al.* (1999 and 2000) and for sprat they have been compiled by Grauman and Krenkel (1986), Karasiova (1999), Krenkel (1981), Köster and Möllmann (2000a). Estimates of the realized daily egg production during main spawning periods were based on stage specific abundance data and temperature related egg development rates (cod: Wieland *et al.* 1994; sprat: Thompson *et al.* 1981).

When using constant maturity ogives as applied by ICES (1996), **cod** SSB is not linearly related to the realized daily egg production; it is however significantly related if based on yearly or periodically adapted maturity ogives (Köster *et al.* 2000). The relation is further enhanced when utilizing only the female part of the SSB or the predicted potential egg production. Apart from methodological problems, the remaining variability may be related to atresia due to unfavourable environmental conditions during spawning (Kjesbu *et al.* 1991), variable fertilization success in relation to salinity changes (Westin and Nissling 1991) and differences in egg mortality already in the first developmental stage. For **sprat** in Sub-division 26 and 28, SSB is significantly related to the realized egg production even when based on constant maturity ogives. Thus, the total spawning stock biomass appears to be a better measure of realized egg production in sprat indicating that inter-annual variability in maturation processes, age-dependent sex ratios and individual fecundity are of less importance. However, the relationship between SSB and potential egg production can be improved substantially by incorporating ambient temperature and growth anomaly from the 3rd to the 2nd quarter in a multiple linear regression. The effect of temperature on realized egg production may have several reasons:

i) low winter temperatures may affect the nutritional condition and growth of sprat,

ii) low temperature in pre-spawning periods may reduce the batch fecundity as well as the batch number (Petrowa 1960), and thus the total seasonal egg production,

iii) low temperatures before and during spawning season may cause a delay in the onset and the peak of spawning activity (e.g., Elwertowski 1960; Grimm and Herra 1984).

Effect of stock structure on viability of cod egg production

Reproductive biology of cod and sprat in the Baltic varies over time and these variations might affect the reproductive output (i.e., viable egg production) of a given stock of mature fish. For instance individual size-specific fecundity, maturity ogives and size/age-specific sex ratios all vary over time and space and between the sexes (see above). Moreover, females within cod stocks (e. g., Northeast Arctic) produce eggs and larvae of different viabilities and spawn at different times and places. In the Baltic, where oxygen conditions at egg incubation depths varies between spawning areas (MacKenzie *et al.* 1999 and 2000), the interaction of cod (and to a lesser extent sprat) stock structure, egg buoyancy and hydrographic factors could be particularly important for egg survival and recruitment (Nissling *et al.* 1998, Vallin *et al.* 1999). Hence spawning stocks composed of different age/size structures could have very different recruit production potentials. Most of these aspects of reproductive biology are not presently considered in current stock assessment procedures in the Baltic yet they could have an impact on perceived levels of fishing mortality that the stocks can sustain. The potential impacts of variations in cod reproductive biology on population viable egg production were therefore investigated using simulation models and empirically observed variations in cod biology (MacKenzie *et al.* 1998). The sensitivity analyses showed that potential egg production was more sensitive to observed variations in fecundity-size relationships and sex ratios than to observed variations in maturity ogives. The uncoupling between population egg production and spawning stock biomass left up to 25% of the variation in modelled egg production unexplained for cod in the central Baltic Sea (ICES Subdivisions 25–32). Disaggregating total egg production by various criteria (e.g., female size, spawning site) could also give improved estimates of the reproductive potential of the Baltic cod population. Resolving egg production spatially (by subdivision) showed that in some years substantial fractions (up to 75%) of the total annual egg production would have been unsuccessful (in terms of recruit production) because eggs were exposed to sub-optimal oxygen concentrations in some spawning areas (Köster *et al.* 1999, Mackenzie *et al.* 1999).

Simple estimates of spawning stock biomass may therefore not be reliable estimates of total egg production and reproductive potential in the Baltic cod stock. Some newer recruitment models using improved egg production estimates that allow for the effects of stock structure on production of eggs having different buoyancy do indeed give better fits to Baltic cod recruitment data than simpler estimates of spawning stock biomass (Jarre-Teichmann *et al.* 2000, Vallin and Nissling 2000).

5.2.5 Developmental success of early life history stages

Survival of cod and sprat eggs and early larvae in relation to ambient abiotic conditions

Survival during early stages is regarded a major bottleneck influencing year class-strength and recruitment in teleosts (Cushing 1990; Brander 1994). In the Baltic, survival during egg and larval stages for both cod and sprat is known to be highly influenced by hydrographic conditions in the spawning areas (Grauman 1973, 1974; Grauman and Yula 1989; Aps 1989; Plikshs *et al.* 1993; Parmanne *et al.* 1994). Spawning of both **cod** and **sprat** occurs in the Baltic deep basins where conditions are highly influenced by the magnitude and frequency of saline water inflows into the Baltic. Due to differences in egg specific gravity, egg development of cod and sprat occurs at different depths; cod eggs being neutrally buoyant at salinities of 12–17 psu (Nissling *et al.* 1994) whereas sprat eggs are known to occur at salinities of 7–13 psu (Grauman 1965), i.e., cod eggs develop in the bottom water under the halocline (Wieland and Jarre-Teichmann 1997), whereas the majority of sprat eggs occur at lower depths, in and above the halocline. This implies that sprat egg survival is less affected by poor oxygen conditions then is survival of cod eggs (Wieland *et al.* 1994). As sprat eggs occur at depths where the water temperature changes during the spawning season (Wieland and Zuzarte 1991, egg and larval development may be influenced by extreme water temperatures. Weak year classes of Baltic sprat have been associated to severe winters accompanied with low water temperatures during peak spawning (Parmanne *et al.*, 1994). Egg development of Baltic cod is normally unaffected by fluctuations in water temperature, but the shift in peak spawning from spring to summer during the 1990s (Wieland *et al.*2000) might involve negative effects of high water temperatures.

Knowledge on the depths of occurrence of cod and sprat eggs, and effects of salinity, temperature and oxygen conditions on egg and larval development is required for understanding of variations in the reproductive success, and for determination of limits for successful reproduction and calculation of reproductive volumes (Plikshs *et al.* 1993; Mackenzie *et al.* 2000). For sprat, information about salinity, temperature and oxygen requirements for successful reproduction is limited, while such information exists for **cod**. However, the definition of reproductive volume (RV) for cod is at present based on minimum oxygen and salinity requirements only, without taking sub-lethal effects into account. Varying the river runoff experimentally resulted in an 50 km^3 increase in RV for cod at 25% decreased river runoff whereas increased river runoff only caused a slight difference compared to the reference model run (STORE 2001). Simulation of an enhanced wind stress (15%) resulted in an additional transport of saline water into the western Baltic but remained due to a more westward oriented return flow basically within the western Baltic. Contrary, 15% less wind stress revealed an increase of the RV because of less developed return flows in the deep layers in the western Baltic. Simulating low near surface water air temperatures in the Skagerrak/Kattegat and western Baltic influencing oxygen solubility, RV increased by around 80 km^3 compared to the reference run when a decrease of the air temperature by 2°C was applied. Thus, processes other than major Baltic inflows had the potential to alter the RV of cod in the Bornholm Basin. Consequently e.g., changes in river runoff regulations and global warming caused by anthropogenic influences will potentially affect spawning conditions for Baltic cod. That RV of Baltic cod is linked to the atmospheric conditions was demonstrated by analysis of changes in the NAO indices (STORE 2001). High positive values of differences in the NAO indices between the first and second half of the winter involve an increase of the RV. Correlating the RV change during winter of given years with the differences in the NAO indices during winter yielded a highly significant relationship.

As the reproductive volume is based on minimum oxygen requirements only, an alternative index has been defined and tested in addition for a more complete utilization of the given information about ambient oxygen conditions in the Bornholm Basin (Köster *et al.* 1999). The oxygen related **cod** egg survival factor, is based on the fraction of the egg production expected to survive each year when applying a laboratory established relation of egg survival on oxygen concentration (Wieland *et al.* 1994; Rohlf 1999), using observed oxygen profiles during spawning time and depth stratified abundance data of cod eggs. The depth distribution of eggs is predicted from the observed water density profiles (Köster *et al.* 1999). A linear regression of egg production at stage III from ichthyoplankton surveys divided by the total potential egg production by the SSB as a measure of egg survival is significantly related this oxygen related egg survival factor explaining 44% of the variance encountered, which is considerably more than explained by the simpler RV.

In an attempt to explain the variability of late cod egg production and larval abundance in the Bornholm Basin, Köster *et al.* (1999) tested various environmental variables for their explanatory power, however, where unable to explain the major part of the variability. This lead to the conclusion that either i) factors other than oxygen and predation related mortality influence the survival until the larval stage, or ii) the variability in larval abundance (integrated over all developmental stages) is too high to detect a major impact of both mentioned factors, or iii) that the abundance estimates of larvae may be biased by inadequate spatial and temporal sampling strategies. Behaviour studies conducted with larvae demonstrated that low oxygen concentration has an impact on larval mortality (Nissling 1994) and that egg incubation at low oxygen impacts on larval activity as well (Rohlf 1999). Furthermore, the experiments revealed that vertical migration into upper water layers is not started before day 4 after hatch. Hence, a significant impact of the environment within and below the halocline on larval survival can be expected. In the more eastern spawning areas, variability in larval abundance was more easily explained, as a highly significant impact of the hydrography is obvious (Köster *et al.* 1999). This result is not surprising as the environmental conditions are less favourable for successful egg survival in these areas compared to the Bornholm Basin (MacKenzie *et al.* 2000).

For **sprat** a significant impact of temperature on egg developmental success has been resolved in the North Sea (Thompson *et al.* 1981) and the Baltic (STORE 2001), with temperatures below 4°C significantly lowering the egg survival success. As these temperatures occur regularly in the intermediate water layer, originating from winter cooling, an effect on egg survival especially after sever winter situations has to be expected and may explain the impact of temperature on sprat recruitment described by Ojaveer (1989) and MacKenzie (1997). An exploratory analysis conducted by Köster *et al.* (2000) for sprat in Sub-division 26 and 28, identified the temperature in the intermediate water as the only sensible factor impacting sprat survival from the larval (derived from ichthyoplankton surveys) to the 0-group stage (from MSVPA). Neither the oxygen condition in deep water layers; wind speed anomaly and larval transport index explained a significant part of the variance encountered in 0-group recruitment. The impact of winter and spring temperature on sprat larval abundance has been described earlier by Grauman and Yula (1989). They identified additionally the solar activity and the spawning stock biomass (as a measure of egg production) as significant factors impacting larval abundance. Other variables as deep-water temperature, salinity and oxygen concentration had an intermediate effect on larval abundance. The impact of temperature on larval abundance is nevertheless by these authors explained by a coupling to the availability of *T. longicornis* as a thermophil prey species for sprat larvae (Grauman *et al.* 1986; Kalejs and Ojaveer 1989).

Predatory interactions

The upper trophic levels of the open sea ecosystem of the Central Baltic are characterized by cod as the major piscivore and the clupeids sprat and herring as abundant planktivores. Biological interactions within the system have been supposed to establish either a cod-dominated or a sprat-dominated system (Rudstam *et al.* 1994), whereas the population development of herring appears to be relatively independent. The first system state is maintained by an intensive cod predation on sprat (e.g., Sparholt 1994), whereas high stock levels of sprat may be able to control the cod stock via predation on eggs (Köster and Möllmann 2000a). Consequently further prerequisites for sustaining the system in the sprat dominated state, are unfavourable reproductive conditions for cod in the Gdansk Deep and the Gotland Basin. Destabilization of the system is caused either by unfavourable hydrographic conditions for reproduction and subsequent recruitment failure of one of the species, or high mortalities caused by the fishery (Schnack 1997). A corresponding shift in the state of the system was observed in the Central Baltic within the period of 1977 to 1996. Due to a combination of high fishing pressure and lacking inflows from the North Sea, the cod stock was reduced from high levels in 1979–1984 to its lowest stock size on record in 1992 (e.g., Bagge *et al.* 1994). The preferred prey species sprat showed a significant increase in population size from 1988 to highest levels on record in 1995 (ICES 1999a), caused by a combination of high reproductive success, reduced predation pressure and relatively low fishing mortalities.

A substantial predation on **cod** eggs by clupeids has been described for the major spawning area of the cod stock, i.e., the Bornholm Basin. Egg predation is most intense at the beginning of the cod-spawning season, with sprat being the major predator (Köster and Möllmann 1997). At this time of the year spring spawning herring concentrate in their coastal spawning areas. Hence they do not significantly contribute to the predation-induced egg mortality at this time of the year. Sprat spawn in the Bornholm Basin from March to July, thus concentrating in cod spawning areas in times of high cod egg abundance. After ceased spawning activity a part of the sprat population leaves the area and remaining individuals switch from copepods and fish eggs to cladocerans as main prey organisms. With the return of the herring from the coastal areas to their feeding grounds in the Bornholm Basin, the predation on cod eggs by herring increases to considerable levels, especially after the peak spawning time of cod shifted to summer month (Wieland *et al.* 2000). A decline in sprat predation on cod eggs was observed in early summer 1993–1996 despite of relatively high cod egg abundances, partly explainable by a shallower distribution of the cod eggs caused by increased salinity after the 1993 major Baltic inflow as well as a deeper distribution of the clupeids due to enhanced oxygen concentrations (Köster and Möllmann 2000a). Beside the above mentioned interactions intensifying the dominance of one or the other species, compensatory biological effects, i.e., cannibalism, are limiting the stock developments. This has been intensively studied for the Central Baltic cod stock (Neuenfeldt and Köster 2000; Uzars and Plikshs 2000).

With respect to **sprat** egg cannibalism, a comparison of estimated sprat egg consumption rates with standing stocks and production rates of sprat eggs revealed a decrease in predation pressure since 1993 (Köster and Möllmann 2000b). These results suggest cannibalism to be an important source of sprat egg mortality at times in the Bornholm Basin. Consumption by herring is of minor importance, as herring predator population sizes are low in the sprat spawning area during main sprat spawning time. Contrary to the Bornholm Basin, predation on sprat eggs appears to be no major source of egg mortality in the more eastern spawning areas. The intensive cannibalism on sprat eggs in the Bornholm Basin prior to the last major Baltic inflow in 1993 may explain the stable sprat stock sizes in Sub-division 25, concurrently to a significant increase in other areas of the Baltic monitored by international hydroacoustic surveys. In most recent years, when egg cannibalism was reduced, reproductive success in Sub-division 25 increased and resulted in highest recruitment of 0-group sprat on record in 1994 and 1995. Larvae of cod and sprat were obviously not substantially affected by predation through clupeids (Köster and Möllmann 1997), independent of the area and date of investigation. This can be explained by a limited vertical overlap of prey and predator, as only newly hatched larvae concentrate in relatively high quantities within or below the halocline, where they are available as prey to herring and sprat aggregating in these water layers while feeding. A substantial predation by adult herring on young of the year sprat was encountered in Sub-division 26 in autumn 1997 (Patokina and Feldman 1998). This process has never been described in this intensity before and may be related to the outstanding high abundance of young of the year sprat in this area and the small average size of the sprat.

Prey availability for cod and sprat early life history stages

Investigations on the seasonal vertical as well as horizontal distribution of mesozooplankton in the Bornholm Basin in 1999 (STORE 2001) revealed seasonal trends in abundance to be characterized by the general life-cycle patterns for the abundant meso-zooplankton species. The univoltine *P. elongatus* (Line 1979 and 1984) had a peak in abundance in April and May, clearly visible from a shift in stage-structure from April (high copepod egg, CI-III and CVI abundance) to May/June (increasing CI-III and CIV as well as decreasing CVI abundance). Conversely *T. longicornis* and *Acartia* spp. having multiple generations accumulated CVI in June to produce next summer generations. *C. hamatus*, preferring higher temperatures (Ackefors and Hernroth 1970; Sidrevics 1984) as well as O. similis were found in lower quantities early in the season having their peak abundances later in the year. The rise of cladoceran abundance from April to June illustrates the affinity of this taxonomic group to increased temperature (Dippner *et al.* 2000; Möllmann *et al.* 2000). Horizontal distribution patterns of *P. elongatus* in the Bornholm Basin are associated with their vertical distribution. CVI preferring higher salinities (Dippner *et al.* 2000; Möllmann *et al.* 2000) were found in deeper parts of the water column. This explains the concentrations in the centre of the Basin, whereas younger stages were found in shallower depths where they will be moved by currents to shallower regions. In contrast, *T. longicornis* and *Acartia* spp, not confined to high salinities but to warmer waters, were generally found in the upper 50m of the water column and thus are distributed in shallower regions. Nauplii of *C. hamatus* were observed mainly in the centre of the Basin, which suggests a spawning in deeper layers similar to *P. elongatus*. This is confirmed by the CVI distribution in May, however not in April and June. Also the vertical distribution showed no CVI to dwell in deeper layers. The general concentration of *O. similis* is similar to *P. elongatus* associated with their deeper distribution, whereas cladocerans dwelling in the upper water layer were found all over the Basin.

Larval diet composition

Copepod nauplii and copepodites are the dominating prey organisms of **cod** and **sprat** larvae in the Central Baltic (Zuzarte *et al.* 1996, STORE 2001). The importance of these items as food for cod larvae has been described by several authors for different regions (Goodchild 1925; Wiborg 1948; Last 1978; van der Meeren and Næss 1993; Fossum and Ellertsen 1994). Larger sprat larvae (>16 mm) also included cladocerans in higher numbers in their diet, a fact not to be observed for cod larvae. This might be explained by different vertical distribution patterns of the larvae. In contrast to other stocks outside the Baltic, phytoplankton does not contribute a relevant proportion to the cod and sprat larval diets. This is confirmed by results obtained from eastern Baltic spawning areas for cod larvae in 1978–1985 (Graumann *et al.* 1989). This difference might be explained by the special environmental conditions in the Baltic, which lead to a temporal as well as spatial mis-match of larvae and high abundances of the above-mentioned phytoplankton. In the central Baltic the bloom of diatoms can be expected from the end of March to the beginning of May (Schulz *et al.* 1992), i.e., before larvae occur in substantial numbers in the plankton. The abundance of dinoflagellates in spring, also suitable as food for larvae, has increased in recent years (Anon. 1996). However, abundance values are still rather low, especially in 1987 and 1988 (Anon. 1996). The second bloom of diatoms occurs in general in October/November being to late to be used by larvae as a food resource of considerable importance. For cod larvae, additionally to this temporal mis-match, the spatial overlap during spring is also rather limited, i.e., highest concentrations of diatoms are encountered in 5–15 m depth (Dahmen 1995), whereas feeding cod larvae show highest concentrations at ca. 30 m depth and only very few are found in the upper 15 m of the water column (Grønkjær and Wieland 1997). An observed shift from nauplii to copepodite/adult copepod feeding in both species is related to different factors: with increasing length and age of the larvae the swimming ability as well as the mouth size increase. The larvae become able to cope with larger prey organisms. The increase in suitable prey size is more pronounced for cod larvae than for sprat larvae. The dominating role of nauplii as food organisms in spring, even in the bigger size classes, can be explained by low abundance of copepodites in this time of the year (Krajewska-Soltys and Linkowski 1994; Dahmen 1995).

Variation in physical processes influencing the feeding environment and distribution of early life stages

The relevance of meso-scale ocean processes in the Baltic Sea, and the climatic conditions driving them, has become increasingly important for explaining recruitment variability of the two key fish species cod and sprat (e.g., Hinrichsen *et al.* 2001a,b; Köster *et al.* 1999; St. John *et al.* 2000). Furthermore, ocean processes influence the physical environment conducive for successful egg development as well as the feeding environment of critical early life history stages. Survival during these early life history stages is determined primarily by the availability of food for growth, by predation, and by transport to and retention in optimal environments. Upwelling has been identified as a key process having the potential to influence recruitment success by changes of the feeding environment due to variation of plankton productivity and aggregation (e.g., Borja *et al.* 1996), while small-scale turbulence enhances encounter rates between larval fish and their prey (e.g., Rothschild and Osborn 1988; MacKenzie *et al.* 1994).

From averaged 3-D physical model (Lehmann 1995) output there is a clear tendency, that along the northern and western coasts of the Baltic Sea, upwelling occurs in a distance of about 20–30km offshore, while along the eastern and southern coast downwelling areas can be detected. Wind induced upwelling associated with stability and with shallow but pronounced stratification of surface waters results in enhanced plankton productivity and aggregation around the thermocline. The corresponding offshore transport (Ekman) of coastal waters might play another important role in the enhancement of biological productivity in the Baltic. In contrast, the direct consequences of downwelling are: low stability and stratification, and less intense and less shallower thermoclines than under upwelling conditions. Furthermore, nutrients and plankton are transported and dispersed within a wider range of the water column. Prevailing downwelling conditions in the south probably implies a general drop of plankton production in the offshore-located spawning grounds of cod and sprat in the Bornholm Basin. Time series of quarterly accumulated positive vertical transports (upwelling) showed that during the second quarter upwelling was predominant within the southern coastal area, especially for the time period prior to the 1980s (STORE 2001). Compared to the 2nd quarters of the years, from July to September (late cod spawning) the spatial occurrence of upwelling regimes changed. Due to enhanced wind stress of mainly western direction, upwelling is more likely at the northern coast. The same tendency of decreasing upwelling intensity for late 1980s and 1990s as for the second quarters is also clearly visible for the late cod-spawning season.

Jarre-Teichmann *et al.* (2000) demonstrated, that the cumulative wind energy at peak spawning time impacts on **cod** recruitment success. The suggested process being a transport of larvae and pelagic juveniles to coastal nursery habitats during periods of high transport and a retention in the central basins during periods of low wind stress of variable wind direction (Hinrichsen *et al.* 2001a). Köster *et al.* (1999) incorporate these transport processes in their exploratory analysis on cod recruitment processes by modifying the wind energy index to consider explicitly the direction of transport (larval transport index). Hydrodynamic modelling studies by Voss *et al.* (1999) and Hinrichsen *et al.* (2001a) demonstrated that larval drift towards the west and north is caused primarily by winds of westerly and southerly direction, whereas winds of opposite direction result in larval transport to the south and east. Periods of low wind energy or varying directions are in turn causing retention in spawning areas.

Larval survival in relation to temporal and spatial variability in feeding environments

Variability in growth and mortality in most marine fishes is known to cause fluctuations in recruitment (Houde 1989; Pepin and Myers 1991). The growth and mortality of marine fish larvae depend on body size, food availability and temperature (Houde and Zastrow 1993). Other studies suggest that advection into or out of areas with optimal environmental feeding conditions accounting for variations in recruitment success (e.g., Werner et al 1993; Köster *et al.* 1999). Hence, a coupled preliminary hydrodynamic/trophodynamic individual based model (IBM) of drift and feeding designed to examine growth and survival of Baltic larval **cod** was developed (STORE 2001). The coupled hydrodynamic/trophodynamic model simulated the encounter of food, foraging, growth and survival of individual cod larvae along their drift routes in the Baltic Sea. In the model, along the drift trajectories the larvae's environment consists of prey availability and temperature influencing the developmental duration of specific larval stages. The model includes a three-dimensional circulation model, and a bioenergetically-based individual model, which tracks larval stages of Baltic cod through space and time. The model is able to assess the overall influence of small-scale turbulence on encounter rates, but does not consider that turbulence can either have an overall beneficial or an overall detrimental effect on larval fish ingestion rate depending on the magnitude of the turbulence and on larval behaviour. Model results suggest the necessity of co-occurrence of peak prey and larval abundances as well as favourable oceanographic conditions for high survival rates. Furthermore, because of the strong decline of the *P. elongatus* stock during the last two decades, it appears that cod changed from a non food-limited to a food-limited state. As derived from long-term zooplankton data, prey concentrations strongly vary in time and space if considering different prey fields (with or without *P. elongatus*). If *P. elongatus* is included, highest survival rates occurred during spring and early summer, whereas omitting *P. elongatus* as prey species only late hatched larvae had higher chances to survive.

Identification of critical early life history stages

Following Paulik's (1973) approach Köster *et al.* (2000) examined the life history process for critical periods and relationships between successive life stages. Only few attempts have been made to follow this approach (walleye pollock in Shelikof Strait, see e.g., Kendall *et al.* 1996, North Sea plaice, see e.g., Beverton and Iles 1992). A large amount of multi-disciplinary information is required and in all cases, including the Baltic, the major problems are lack of time series data of key processes and the variety and complexity of processes involved.

From regression analyses of daily production rates of early egg developmental stages on later development stages up to recruitment at age 1, critical periods for **cod** recruitment appear to be the late egg to the larval stage and also the correlation between production rates of young and old egg stages. Lowest egg survival rates were estimated for early to mid 1980s, a period for which the number of missing data is largest. Larval abundance per advanced egg stage production was lowest in the period 1992 to 1996, indicating extremely low viable hatch or larval survival in these years. Highest survival on the other hand is indicated for 1985, a year with low egg survival Cod larval abundance derived by ichthyoplankton surveys is highly correlated to MSVPA derived 0-group recruitment.

For **sprat**, in contrast to cod, the relations between production estimates of early and late egg stages as well as between late egg stage production and larval abundance are highly significant for both Sub-divisions 26 and 28, This indicates that mortality during the egg and early larval stage is less critical for the reproductive success of sprat compared to cod. Larval abundance of sprat is, again in contrast to cod, hardly related to 0-group abundance. As explained above, the maturation process related to the structure and condition of the adult stock is a first critical part in Baltic cod recruitment. The poor correlation between late egg stage production and larval abundance in cod has been identified only recently (Köster *et al.* 2000). However, already Plikshs *et at.* (1993) pointed out, that egg survival is highly correlated to the reproductive volume, but year-class strength is not, indicating that other processes affect recruitment as well. Larval survival in dependence of egg quality characteristics (Nissling *et al.* 1998; Petersen *et al.* 1997), egg incubation at low but not lethal oxygen concentrations during egg incubation (Rohlf 1999), food supply for initial feeding (Plikshs *et al.* 1993, STORE 2001) and transport to favourable nursery areas (Hinrichsen *et al.* 2001a) are additional potential variables affecting early larval survival (see above). The close correlation between larval abundance and 0-group recruitment suggests, however, that a major part of the variability in recruitment is introduced already in the late egg and early larval stage.

5.3 Considerations for a Conceptual Model

This section attempts to structure and rank the importance of processes identified in Section 5.2, with focus on the impact of environmental fluctuations on stock dynamics. Indirect and direct effects of fishing activities and endogeneous processes are not considered here in order to simply the overview. The ranking for herring is based on the expertise available within the present group only, as an extended literature review as performed for both other species is still pending.

Temperature changes due to fluctuations in winter severity and the frequency and intensity of inflows of saline, oxygenated water from the North Sea and the Danish Straits have been identified as major processes affecting ambient environmental conditions. Thus, three environmental scenarios were assumed: (SQ) *status quo*, i.e., relatively mild winter and no inflow situations, (VT) variable and on average colder temperature conditions caused by a series of very cold winters, and (VI) variable inflow conditions.

Relevance of processes in the Central Baltic proper in relation to prediction models under different environmental scenarios

An example how to read the table: under status quo environmental conditions (A), in short term predictions the relevance of population distribution in relation to medium-term catch predictions for cod (co) is intermediate (o), while it is high (+) under inflow conditions. Other abbreviations are: he: herring, sp: sprat, -: considered to be of low importance. Short-term predictions: forecast of catch for the year following the assessment year and SSB for the subsequent year, medium-term projection: 1–2 generation times ahead, long-term projections: several generation times ahead.

		Relevance for…														
		Short term						**Medium term**						**Long term**		
		Catch			**Stock**			**Catch**			**Stock**			**Stock**		
Process	**Case**	**co**	**he**	**sp**	**co**	**he**	**sp**	**co**	**he**	**sp**	**co**	**he**	**sp**	**co**	**he**	**Sp**
Population spatial distribution	**SQ**	-	-	-	-	-	-	o	+	o	o	o	o	o	+	O
	VT	-	+	o	-	-	o	o	+	o	-	-	o	-	-	+
	VI	o	O	o	o	-	-	+	+	o	+	-	o	+	-	O
Foraging (being eaten) [M2, predation mortality]	**SQ**	-	o	o	-	+	+	o	+	+	o	+	+	+	+	+
	VT	-	o	o	-	+	o	o	+	+	o	+	+	+	+	+
	VI	-	o	o	-	+	+	o	+	+	o	+	+	+	+	+
Growth [weight at age]	**SQ**	-	o	-	o	o	-	o	+	o	o	+	o	+	+	+
	VT	-	o	o	o	o	o	o	+	+	+	+	+	+	+	+
	VI	-	o	-	o	o	-	+	+	o	+	-	o	+	-	+
Timing of spawning	**SQ**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	VT	-	o	o	-	-	o	-	-	o	-	-	o	-	-	o
	VI	-	-	-	-	-	-	o	-	-	o	-	-	+	-	-
Individual maturation [maturity ogive]	**SQ**	-	-	-	-	-	-	o	o	-	o	o	-	+	+	-
	VT	-	-	o	-	-	o	o	o	o	o	o	o	+	+	o
	VI	-	-	-	-	-	-	o	-	-	o	-	-	+	-	-
Individual fecundity	**SQ**	-	-	-	-	-	-	o	o	-	o	o	-	o	o	-
	VT	-	-	o	-	-	o	o	o	+	o	o	+	o	o	+
	VI	-	-	-	-	-	-	+	-	-	+	-	-	+	-	-
Population egg production	**SQ**	-	-	-	-	-	-	o	o	o	o	o	o	o	o	o
	VT	-	-	o	-	-	o	o	o	+	o	o	+	o	o	+
	VI	-	-	-	-	-	-	+	-	o	+	-	o	+	-	o

		Relevance for…														
		Short term						**Medium term**						**Long term**		
		Catch			**Stock**			**Catch**			**Stock**			**Stock**		
Process	**Case**	**co**	**he**	**sp**	**co**	**he**	**sp**	**co**	**he**	**sp**	**co**	**he**	**sp**	**co**	**he**	**Sp**
Individual egg survival	**SQ**	-	-	-	-	-	-	o	+	-	o	+	-	o	+	-
	VT	-	-	o	-	-	o	o	+	+	o	+	+	o	+	+
	VI	-	-	-	-	-	-	+	-	-	+	-	-	+	-	-
Individual larval survival	**SQ**	-	-	-	-	-	-	o	+	+	o	+	+	o	+	+
	VT	-	-	+	-	-	+	o	+	+	o	+	+	o	+	+
	VI	-	-	-	-	-	-	+	-	+	+	-	+	+	-	+
Individual juvenile survival [recruitment]	**SQ**	-	-	-	-	-	-	o	+	+	o	+	+	o	+	+
	VT	-	o	o	-	+	+	+	+	+	o	+	+	o	+	+
	VI	-	-	-	-	-	-	+	-	+	+	-	+	+	-	+

The table indicates that the only process of importance for short-term predictions of cod is growth independent of the environmental scenario. Additionally, the spatial distribution during inflow scenarios will affect the catch and stock prediction. In contrast, for sprat various processes affecting the recruitment as well as predation mortality and growth are considered of intermediate importance for short-term predictions. In general the complexity of processes affecting the projection of the stock dynamics is considered to increase with length of the prediction time horizon. Here inflow situations are of major importance for cod development in both medium- and long-term projections. The impact of inflow situations is considered to be of limited importance for projections of the herring stock development, but somewhat more important for sprat, while for both clupeid species changes in the temperature regime are ranked to be of major importance.

In Table 5.3.1 the compiled information is utilized to identify necessary actions to include important variables and parameters in multispecies forecasts considering the major processes affecting the stock population dynamics given in the text table above.

Table 5.2.1

Process	Species	Predictor variable	Function	Biological scale	Reference
cannibalism	cod	catches and stomach contents	cannibalism reduces years classes in time of high juvenile and adult densitie	population	Neuenfeldt and Koester 2000
cannibalism	cod	catches and stomach contents	cannibalism reduces years classes in time of high juvenile and adult densitie	population	Uzars and Pliksh 2000
cannibalism	sprat	stomach contents	cannibalism on eggs possibly substantial in Bornholm Basin	population	Koester and Moellmann 2000b
distribution	cod	oxygen	at least 2 ml/l, positive preference	population	Tomkiewicz et al. 1998
distribution	cod	salinity	at least 11, positive preference	population	Tomkiewicz et al. 1998
distribution	cod	temperature	avoidance of surface layer	population	Rechlin 1967
distribution	sprat	salinity	concentrate below halocline	population	Groehsler et al. 2000
distribution	sprat	maturation	independent of maturation	population	STORE 2001
distribution	cod	maturation	dependent on maturation	population	Tomkiewicz et al. 1998
distribution	cod	basin	depletion in 28	population	Sparholt and Tomkiewicz 200
distribution	cod	basin	depletion in 28	population	Aro 2000
egg buoyancy	cod	eggs size	the larger egg the less depth at neutral buoyancy	individual	Nissling et al. 1998
egg development	cod	salinity	neutral bouyancy at 12-17 PSU	individual	Nissling et al. 1994
egg development	cod	water density	neutral bouyancy at water density between 1008-1015 kgm-3	individual	Koester et al. 2001
egg development	sprat	salinity	neutral bouyancy at 7-13 PSU	individual	Graumann 1965
egg development	sprat	temperature	low temperature during incubation decreases year class survival	population	Parmanne et al. 1994
egg development	cod	reproductive volume	time series of RV	population	MacKenzie et al. 2000
egg development	cod	oxygen concentration	survival at sub-lethal oxygen concentration depends on oxygen concentration	individual	Rohlf 1999
egg development	sprat	temperature	survival decreases below temperature og 6 deg. C	individual	Thompson et al.
egg development	cod	salinity	cod eggs concentrate in a narrow depth range below the permanent halocline	population	Wieland and Jarre-Teichmann
egg predation	cod	basin	predation lower in Gotland Basin than in Bornholm Basin	individual	CORE 1998
egg predation	cod	egg abundance and vertical overlap wi	egg mortality linearly related to abundace and overlap	population	Koester and Moellmann 2000b
egg production	cod	basin	high in 25	population	Koester et al. 1999
egg size	cod	female size	the larger females the larger eggs	individual	Nissling et al. 1998
egg survival	cod	oxygen	integrated oxygen content in rv	population	Koester et al. 2001
egg survival	cod	oxygen	oxygen related survival factor	population	Koester et al. 2001
egg survival	cod	development stage and hydrography	state specific egg size model	individual	Bulgakova and Graumann 199
egg survival	cod	ovary contaminant load	hatch rate decreases signifcantly with contaminant load		Pedersen et al. 2000
egg survival	cod	ovary contaminant load	hatch rate does not decrease signifcantly with contaminant load		Schneider et al. 2000
egg survival	cod	development stage	specific gravity chnages during development	individual	Nissling and Vallin 1996
egg survival	cod	salinity and predators	vertical overlap with sprat influences egg mortality in Bornholm Basin	population	Koester et al. 2001
egg viability	cod	size	viability of eggs and larvae positively related to egg size	individual	Nissling et al. 1998
fecundity	cod	temperature, growth rate	relative fecundity varied between years, not between areas or months	individual	Kraus et al. 2000
fecundity	sprat	size	relative batch fecundity independent on female size	individual	Alekseeva et al. 1997
fertilization	cod	malformation rate	fertilization rate not correlated to malformation rate	population	Vallin and Nissling 1998
timing of spawning	cod	size	large fish usually spawn earlier than smaller fish	individual	Kaendler 1944
timing of spawning	cod	size	large fish usually spawn earlier than smaller fish	individual	Bagge abd Steffensen 1991
foraging	cod	catches and stomach contents	cod top predator of sprat	population	Sparholt et al. 1994
foraging	sprat	catches and stomach contents	sprat preys upon cod eggs	population	Koester and Moellmann 2000a
foraging	sprat	stomach contents, predator abundanc	sprat preys upon cod eggs, especially in the beginning of cod spawning	population	Koester and Moellmann 1997
foraging	herring	stomach contents, predator abundanc	preys upon cod eggs, especially in the end of cod spawning	population	Koester and Moellmann 2000a
foraging	sprat	time	predation on cod eggs decreased during 80ies due to delay in cod spawning	population	Koester and Moellmann 2000a
growth	herring	time	decline in weight at age by more than 50 % since early 80ies	population	Raid and Lankov 1995
growth	herring	food	decline in weight at age due to food limitation	population	Cardinale and Arrhenius 2000
growth	herring	food	decline in weight at age due to competition with sprat	population	Cardinale and Arrhenius 2000
growth	herring	stock composition	decline in weight at age due to different mixture of sub-components with differ	population	Ojaveer 1989
growth	herring	stock composition	decline in weight at age due to different mixture of sub-components with differ	population	Sparholt 1994
growth	herring	predation	size selective mortality	individual	Beyer and Lassen 1994
growth	sprat	predation	no size selective mortality at age for sprat because size at age overlaps	population	ICES 1997
growth	sprat	predation	no decline in weight at age due to different mixture of sub-components with di	population	Ojaveer 1989
growth	sprat	predation	weight at age significantly correlated to food availability and daily ration	population	Moellmann 2001
larval abundance	cod	late egg stage production	weak correlation between egg production and larval abundance	population	Koester et al. 1999
larval abundance	cod	reproductive volume	weak correlation between reproductive volume and larval abundance	population	Pliikshs et al. 1993
larval drift	cod	wind	larvae drift from Bornholm to Gdansk Deep	population	Aro et al. 2001
larval drift	cod	wind	drift influences larval distribution and feeding environment	individual	Hinrichsen et al. 2001 a,b
larval drift	cod	wind	drift influences recruitment	individual	Jarre-Teichmann et al. 2000
larval foraging	cod	wind	small scale turbulence increases encounter rate with planktonic prey	individual	MacKenzie et al. 1994
larval foraging	cod	salinity	P. elongatus abundance depends on high salinity	population	Ojaveer et al. 1999
larval foraging	cod	salinity	P. elongatus abundance depends on high salinity	population	Vuorinen et al. 1998
larval foraging	cod	temperature	P. elongatus abundance depends on low temperatures in summer	population	Moellmann et al. 2000
larval foraging	cod	temperature	Temora, Acartia and Cladocerans increase instead at high temperature	population	Moellmann et al. 2000
larval foraging	cod	temperature	Temora, Acartia and Cladocerans increase instead at high temperature and l	population	Sidrevics 1984
larval foraging	cod	stomach data	diet consist of copepod nauplii and at larger size also copepodites	individual	STORE 2001
larval foraging	sprat	stomach data	diet consist of copepod nauplii and at larger size also copepodites	individual	STORE 2001
larval foraging	sprat	stomach data	larger larvae included cladocerans in diet	individual	STORE 2001
larval foraging	cod	depth	feeding larvae show highest concentration at 30 m due to food availability	individual	Grønkjær and Wieland 1997
larval prey availabi	cod	season	seasonal trends due to life cycles pattern of zoo-plankton species	population	STORE 2001
larval prey availabi	cod	depth	increasing abundance of Acartia ssp. And Temora longicornis with depth	population	STORE 2002
larval prey availabi	cod	temperature	cladoceran abundance increases from april to june	population	STORE 2001
larval size	cod	egg size	the larger eggs the larger larvae and the higher growth rate	individual	Vallin et al. 1999
larval survival	cod	larval size	the larger larvae the better survival	individual	Vallin and Nissling 2000
larval survival	cod	female condition	no effect visible	individual	STORE 2001
larval survival	cod	stomach contents	larval survial not affected by clupeid predation	population	Koester and Moellmann 1997
larval survival	sprat	stomach contents	larval survial not affected by clupeid predation	population	Koester and Moellmann 1997
larval survival	cod	oxygen concentration	low oxygen concentration at sub-lethal conditions decreased larval vertical ac	individual	Nissling 1994
larval survival	cod	oxygen concentration	vertical migration in to surface layer is not started before day 4 after hatch	individual	Rohlf 1999
larval survival	cod	prey abundance	food limitation unimportant in central baltic	population	Krajewska-Soltsy and Linkows
larval survival	sprat	temperature	temperature is affecting larval survival for sprat	population	Graumann and Yula 1989
maturation	cod	age	male mature earlier than females (and later in the North-East than in the Wes	individual	Tomkiewicz et al. 1997
migration	cod	spawning	migrate in the basin to spawn	population	Tomkiewicz and Koester 1999
migration	sprat	spawning	leave spawning area after spawning	population	Koester 1994
migration	cod	spwaning	cod migrate from GB to BB	population	Tomkiewicz and Koester 1999
migration	cod	spawning	cod migrate from GB to BB	population	Aro 1989
migration	cod	feeding	age 2 group migrates partially from 26 to 28	population	Pliikshs 1996
overlap	cod and herrin	oxygen and salinity	overlap volume depends on inflows	population	Neuenfeldt 2001
sex ratio	cod	spawning	ratio changes through spawning	population	Tomkiewicz and Koester 1999
spawning	cod	time	timing depends on sex- and age composition, peak does not	population	Tomkiewicz and Koester 1999
spawning	sprat	time	spawns in February to Julywith peak in June, spawning interval ca. 4 days	population	Tomkiewicz and Koester 1999
sperm activation	cod	salinity	minimum salinity is 11	individual	Westin and Nissling 1991
upwelling		wind	occurs along northern and western coast ca. 20-30 km offshore	population	Lehmann 1995

Table 5.3.1 Sources of information and necessary actions to include important variables and parameters in multispecies forecasts considering major processes affecting the stock population dynamics.

Process	**Stock size**	**Stock structure acc. to age**	**Habitat preference**	**Maturity**	**Fecundity**	**Weight at size/age**	**Predator availability**	**Prey availability**	**Prey suitability**	**Consumption rates**	**Predator size at age**	**T**	**S**	**O2**	**Wind**
Spatial distribution[1]	Model output	Model output	Parametri-zation	To be modelled	-	-	? (vertical)	?	-	-	-	Simu-lation	-	Simu-lation	-
Predation mortality (Clupeids)[2]	Model output	Model output	-	-	-	To be modelled & see below[3]	Model output & see above[1]	-	Model output	To be modelled (cod as predator)	To be modelled see below[3]	Simu-lation	-	?	-
Growth[3]	Model output	Model output	-	To be modelled	-	Output	-	Model output for cod, clupeids to be modelled	-	To be modelled	-	Simu-lation	?	?	-
Maturation [4]	Model output	-	-	Output	-	To be modelled see above[3]	-	Model output for cod, clupeids to be modelled	-	To be modelled	-	Simu-lation for sprat	-	-	-
Timing of spawning[)]	-	Model output	-	To be modelled see above[4]	-	-	-	-	-	-	-	Simu-lation for sprat	-	-	-
Individual fecundity	-	-	-	-	Output	To be modelled & see above[3]	-	-	-	-	-	Simu-lation	-	-	-
Population egg production	Model output	Model output	-	To be modelled see above[4]	To be modelled see above[6]	To be modelled & see above[3]	-	-	-	-	-	Simu-lation	-	-	-
Egg survival	-	-	-	-	-	-	Model output & see above[1]	-	-	To be modelled (clupeids as predators)	-	Simu-lation	Simul ation	Simu-lation	-
Larval survival	-	-	-	-	-	-	-	To be modelled	To be modelled	-	-	Simu-lation	-	Simu-lation	Simu-lation
Juvenile survival	-	-	-	-	-	To be modelled & see above[3]	Model output & see above[1]	To be modelled	To be modelled	-	-	-	-	-	Simu-lation

1) Model output: generated already by standard prediction methodology
2) To be modelled: model subcomponents to be constructed
3) Parameterisation: empirical information
4) Simulation: scenario modelling

6 BIOLOGICAL REFERENCE POINTS

The ICES framework for the Precautionary Approach makes use of four reference points: F_{lim}, F_{pa}, B_{lim} and B_{pa}. A precautionary reference point is an estimated value derived through an agreed scientific procedure, which corresponds to the state of the resource and of the fishery, and which can be used as a guide for fisheries management. Two types of precautionary reference points should be used:

- conservation or limit reference points
- management or target reference points.

Limit reference points set boundaries which are intended to constrain harvesting within safe biological limits within which the stocks can produce maximum sustainable yield. Target reference points are intended to meet management objectives. Precautionary reference points should be stock-specific to account for the reproductive capacity, the resilience of each stock and the characteristics of fisheries exploiting the stock, as well as other sources of mortality and major sources of uncertainty.

6.1 Single Species Reference Points

The management of fish stocks in the Baltic Sea area has been the mandate of IBSFC since 1974. The management in principal tries to take into account uncertainties associated with the estimation of the state of stocks and management actions. These uncertainties may appear in retrospective to be deterministic, but predicting the future of a stock always contains unknown or even unknowable factors, which make the predictions uncertain. In the Baltic fish stocks there are many types of variation that affect the stock growth and abundance and thus management is based on single species approach.

IBSFC has established some of the necessary reference points and ICES has proposed some of them, which has not been endorsed by IBSFC.

Baltic Cod

In its twenty-fifth session in September 1999 IBSFC made a resolution to have a specified management strategy on Baltic cod. The resolution contains a long-term management strategy for the cod stocks in the Baltic Sea, which is consistent with the precautionary approach and designed to ensure a rational exploitation pattern and provide for a stable and high yield.

The IBSFC agreed to implement a long term management plan for the two cod stocks, Eastern and Western stocks, as defined by ICES, which is consistent with a precautionary approach and designed to ensure a rational exploitation pattern and provide for stable and high yield. The plan consist of the following elements:

1. Every effort shall be made to maintain a minimum level of Spawning Stock Biomass (SSB) greater than 160 000 tonnes for the Eastern stock and 9 000 tonnes for the western stock.
2. A long term management plan, by which annual quotas shall be set for the fishery on the Eastern stock, reflecting a fishing mortality rate of 0.6 and for the Western stock 1.0 for appropriate age groups as defined by ICES shall be implemented.
3. Should the SSB fall below a reference point of 240 000 tonnes for the Eastern stock and 23 000 tonnes for the Western Stock, the fishing mortality rates referred to under paragraph 2, will be adapted in the light of scientific estimates of the conditions then prevailing, to ensure safe and rapid recovery of spawning stock biomasses to levels in excess of 240 000 tonnes and 23 000 tonnes respectively for the Eastern and Western Stocks.
4. For allocation purposes, a combined TAC will be established; The Contracting Parties agree to further collaborate, *inter alia*, through bilateral agreements to ensure an efficient management of the cod stocks.
5. The exploitation pattern in the fisheries for cod and in particular, the selectivity shall be improved in the light of new scientific advice from ICES with the objective to enhance the spawning biomass of cod and reduce discards.
6. Additional technical measures including, *inter alia*, further limitation on effort, restrictions on fishing days, closing of areas and / or seasons, obligation to change fishing ground in case of high abundance of juveniles, special reporting requirements, and other appropriate control measures should be considered.
7. The IBSFC shall, as appropriate, adjust management measures and elements of the plan on the basis of any new advice provided by ICES.

A review of this arrangement shall take place no later than year 2003.

For the western Baltic cod stock, ICES has proposed the previously established MBAL (23 000 t) as B_{pa} and proposed to base B_{lim} on the historical low SSB.

As the latter value is found in the years where the catch data are considered unreliable, the proposed value by ACFM in 1998 of 9 000 t was withdrawn as the B_{lim}. As there is doubt whether the recent assessment reflects actual fishing mortality on the western Baltic cod, an F_{pa} should therefore be discussed with relevant management bodies.

For the eastern Baltic cod stock ICES (1999) considered and proposed a B_{lim} of 160 000 t and B_{pa} to be set at 240 000 t. For fishing mortality the corresponding values were F_{lim} = 0.96 and F_{pa} = 0.6.

Because ICES did not define all the necessary reference points, IBSFC has adopted them from a preliminary suggestion and proposals. Obviously the basic conditions for management strategies attempts.

Baltic herring:

For herring in the Sub-divisions 25–29 and 32 (including Gulf of Riga the following reference points has been considered and proposed by ICES and technical basis is as follows:

ICES considers that:	ICES proposes that:
$\mathbf{B_{lim}}$ **Not defined**	$\mathbf{B_{pa}}$ **Not defined**
$\mathbf{F_{lim}}$ is 0.33	$\mathbf{F_{pa}}$ be set at 0.17

Technical basis:

$\mathbf{B_{lim}}$ **Not defined**	$\mathbf{B_{pa}}$ **Not defined**
$\mathbf{F_{lim}}$: $\mathbf{F_{loss}}$	$\mathbf{F_{pa}}$: $\mathbf{F_{med}}$

For herring in the Sub-divisions 30 the following reference points has been considered and proposed by ICES in 2000 and technical basis is as follows:

Reference points proposed by ICES in 2000:

ICES considers that:	ICES proposes that:
$\mathbf{B_{lim}}$ is 145 000 t	$\mathbf{B_{pa}}$ be set at 200 000 t
$\mathbf{F_{lim}}$ is 0.30	$\mathbf{F_{pa}}$ be set at 0.21

Technical basis:

$\mathbf{B_{lim}}$: spawning stock biomass, where probability of lower recruitment increases	$\mathbf{B_{pa}}$: $\mathbf{B_{lim*}}$ exp(1.645*0.2)
$\mathbf{F_{lim}}$: $\mathbf{F_{loss}}$	$\mathbf{F_{pa}}$: $\mathbf{F_{med}}$

Baltic sprat:

For sprat in the subdivisions 22–32 the following reference points has been considered and proposed by ICES and technical basis is as follows:

ICES considers that:	ICES proposes that:
$\mathbf{B_{lim}}$ is 200 000 t	$\mathbf{B_{pa}}$ be set at 275 000 t
$\mathbf{F_{lim}}$ is not yet defined	$\mathbf{F_{pa}}$ be set at 0.40

Technical basis:

$\mathbf{B}_{lim}$: MBAL	$\mathbf{B}_{pa}$: $\mathbf{B}_{lim}$*1.38; some sources of uncertainty in assessment taken into account
$\mathbf{F}_{lim}$: –	$\mathbf{F}_{pa}$:~ average $\mathbf{F}_{med}$ in recent years, allowing for variable natural mortality

$\mathbf{F}_{pa}$ has been revised compared to ICES proposal in 1999.

It should be mentioned that all single species reference points have been endorsed and/or proposed according to stock/assessment units and the management units used by IBSFC do not match these units in case of Baltic cod and herring.

At present the IBSFC TAC management areas are:

Baltic cod:

1) The Whole Baltic (Sub-divisions 22–32)

Baltic herring:

1) The Western Baltic, the Main Basin and Gulf of Finland (Sub-divisions 22–29S including Gulf of Riga and 32)
2) Management unit III (Sub-divisions 29N; 30 and 31)

Sprat:

1) The Whole Baltic (Sub-divisions 22–32)

6.2 Multispecies Reference Points

We consider two main types of multispecies reference points, those that treat a number of species simultaneously (a traditional multispecies approach) and those that integrate aspects of a number of species into a single metric (an ecosystem approach). An example of the traditional approach is (Gislason 1999) in which he has developed a model for the Baltic community. In this approach the total yield of the system is compiled and the fishing effort is distributed over the three species.

Reference points for one species depend upon those of the others. In the ecosystem approach, instead of addressing the 3 species as a group, an ecosystem metric is defined which integrates some aspects of the 3 into a single metric. This metric would be compared to its own reference point/target and would reflect the system's quality rather than that of individual components. The ICES Working Group on Ecosystem Effects of Fishing WGECO defined such indices, which could be used as metrics of ecosystem quality.

Gislason (1999) proposed single species and multispecies reference points for Baltic fish stocks. A single species reference point, say F0.1, goes from a point to a (curved) line or region in the multispecies context. He warns about considering stocks in isolation and that considerable changes to limits are seen when multispecies interactions are included. The Study Group's projections in Section 4 confirmed Gislason's results in that all three species cannot attain a high biomass, greater than the respective Bpa's.

The ICES Working Group on Ecosystem Effects of Fishing WGECO defined indices which could be used as metrics of ecosystem quality, called EcoQ's. For EcoQ's there would have to be objectives defined and these are called EcoQO's. These indices and objectives would complement single species indices in managing and monitoring an ecosystem. The following definitions and paragraph are taken from their report with the internal citations omitted. Interested readers are referred to the original for more detail and discussion.

Ecological Quality (EcoQ): *An overall expression of the structure and function of the marine ecosystem taking into account the biological community and natural physiographic, geographic and climatic factors as well as physical and chemical conditions including those resulting from human activities.*

Ecological Quality Objectives (EcoQO): *The desired level of ecological quality relative to a reference level*

Reference points: In ICES advice regarding fisheries, reference points are specific values of measurable properties of systems (biological, social, or economic) used as benchmarks for management and scientific advice. They function in management systems as guides to decisions or actions that will either maintain the probability of violating a reference point below a pre-identified risk tolerance, or keep the probability of achieving a reference point above a pre-identified risk tolerance There will be multiple reference points for any single property of a system, each serving a specific purpose. In advice on non-fisheries issues, ICES terminology has been somewhat more variable, with reference **value** used in contexts identical to those where reference point is used in advice on fisheries. CDAGV should resolve these terminological inconsistencies as quickly as possible.

Criteria for good Ecological Quality metrics (EcoQs)

The concept of ecological quality objectives (EcoQOs) has been discussed in a number of documents and at a number of recent meetings. Several key features of EcoQ metrics may be derived from these discussions. These may be summarised as follows:

Metrics of EcoQs should be:

- Relatively easy to understand by non-scientists and those who will decide on their use
- Sensitive to a manageable human activity
- Relatively tightly linked in time to that activity
- Easily and accurately measured, with a low error rate
- Responsive primarily to a human activity, with low responsiveness to other causes of change
- Measurable over a large proportion of the area to which the EcoQ metric is to apply
- Based on an existing body or time-series of data to allow a realistic setting of objectives

In addition an EcoQ metric may:

- Relate to a state of wider environmental conditions.

These eight properties were all deemed desirable in a metric of EcoQ but were not all regarded as essential properties. The eighth was considered to refer to the information content of the metric rather than being a necessary quality. We therefore do not employ this criteria in our screening process.

To illustrate some of these characteristics two ecosystem indicators were proposed for a preliminary trial in the 4M model. These indices would be estimated historically in the MSVPA phase and then for projections at a lower level of fishing pressure Fpa on all three Baltic stocks. See Section 4.2 for details of the projection.

1) Mean weight summed over the three species in the model.
2) Ratio of cod to sprat biomass in model (highest and lowest trophic levels in the model).

These metrics were proposed because of their simplicity to calculate rather than their probable quality as ecosystem indicators. Figure 6.2.1 shows the biomass trends for the 3 species on the upper panels and the two ecosystem indices in the lower for 1974–2000. The mean weight in the ecosystem (Wbar Eco) was not very responsive though the biomasses of the individual species under considerable change. The biomass ratio of cod to sprat biomass (Cod/Sprat Eco) was quite sensitive and may be a useful indicator of ecosystem balance. Figure 6.2.2 shows the two ecosystem indicators for the 30-year forecast. Again, the cod/sprat ratio is more sensitive and potentially a more useful metric of ecosystem status.

Time constraints precluded further investigation of these indices. The roles of ecosystem and multispecies indices and objectives require further research.

Considering only 3 species from the ecosystem may not be sufficient to assess the role of ecosystem indicators for the Baltic Sea.

Figure 6.2.1 A comparison of ecosystem and single species indicators. The top three plots are cod, herring and sprat total biomass; the lower two are ecosystem indicators which are the average weight in 3 species system and the ratio of cod to sprat biomass.

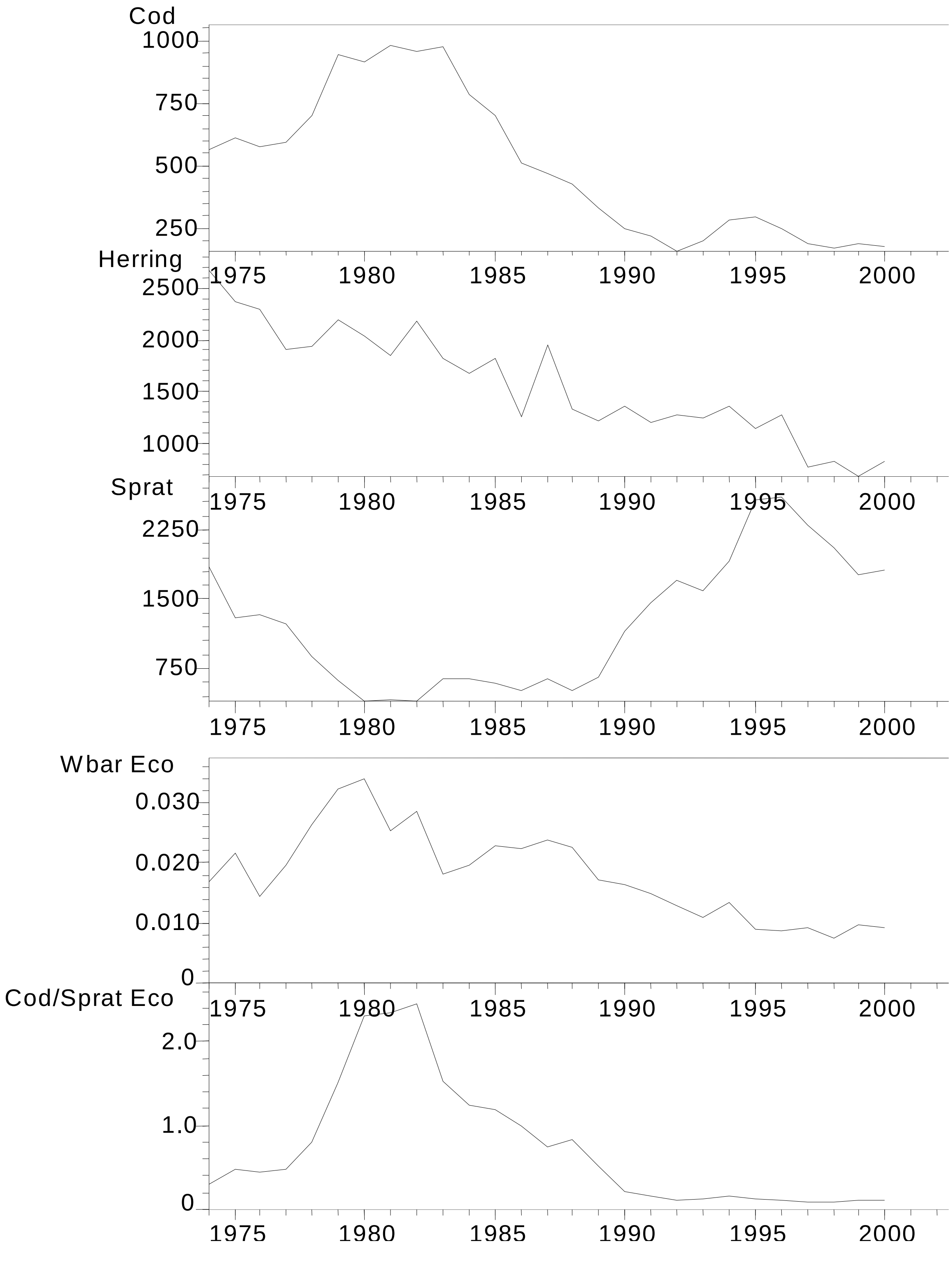
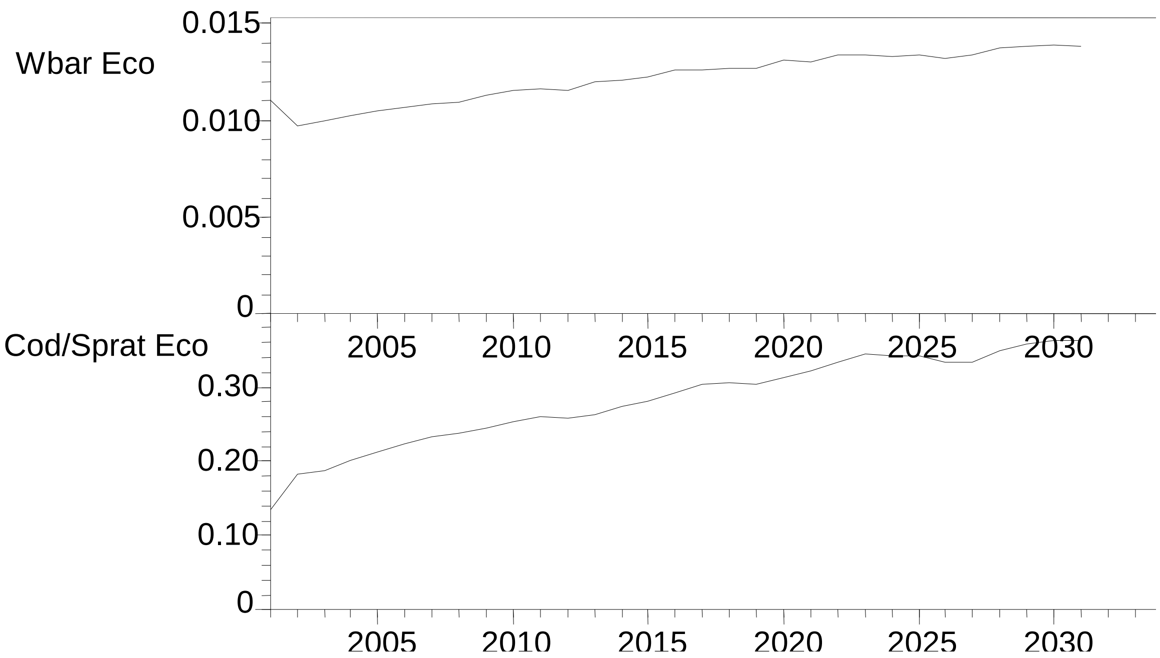


Figure 6.2.2 Ecosystem indices for 30 year projection at Fpa for all three stocks. See section 4.2 for details of forecast.



7 FUTURE DEVELOPMENT AND USE OF MULTISPECIES MODEL IN THE BALTIC

7.1 Description of Future Tasks in 2001 and 2002

Because SGMPB is heavily dependent on development and outcome of various projects outside ICES, SGMPB considers that it is premature to propose any terms of reference for its next meeting,. However, SGMPB also considers that it is necessary to keep the capability of running multispecies models for the Baltic within the ICES community and should ensure further progress in multispecies modelling in the Baltic. In order to achieve this, following activities are needed in 2001 and 2002.

To promote the utilization of the MSVPA by the Baltic Fisheries Assessment Working Group as a standard assessment tool, the following activities are needed before the next Working Group meeting in April 2002:

- Installation of the 4M programme package as well as necessary data-bases on ICES computer system. 4M is currently ready for such implementation.
- Plan in 2001 and organize a training workshop in 2002 preceding WGBFAS meeting to increase the theoretical and practical skills of WGBFAS members on multispecies modelling issues in the Baltic.

In WGBFAS 2001 meeting, the stock assessment units of Baltic herring have been elaborated in order to achieve a better resolution of the local stock's dynamics. In order to assess the new stock units WGBFAS used MSVPA database to have necessary information for single stock assessments.

To have database revisions and to develop procedures for regular database update needs allocation of effort. Expanding the database backwards in time to cover 1960s and 1970s requires additional effort. In the present framework, this is not possible and thus it is necessary to explore in 2001 possibilities to set up an internationally co-ordinated project on compilation, validation and maintenance of basic multispecies assessment data for the Baltic stocks: The main aim of such a project should be as follows:

- validation of the newly compiled catch at age and weight at age in the catch data-base for the period 1974–1992 according to quarter and sub-division as a pre-requisite for finalization of a common multi- and single species assessment database in the Baltic
- exploration of the possibilities to expand the data-base back in time to 1960s and early 1970s including stomach data
- set-up of a data-base on weight at age in the stock derived from historical and ongoing research survey activities
- outline strategies and procedures for annual updating and maintenance of the database.

As basis of constructing environmentally based short-term prediction and medium- to long-term projection models, it is necessary to review available information on environmental processes affecting the population dynamics of cod, sprat and herring. For cod and sprat this review was completed in during this meeting. For herring a similar exercise is planned to be carried out inter-sessionally in 2001 and 2002. The aim is to:

- incorporate Baltic herring expertise into the SGMPB not available presently
- structure and rank the relevance of major processes for predictions on different time scales under different environmental scenarios for Baltic herring stocks
- give sources of information and necessary actions to include important variables and parameters in multispecies predictions

The development, application and validation of different types of multispecies prediction models, which take into account environmental processes affecting prey selection and total food intake, growth, maturation and egg production as well as subsequent recruitment success have not been completed yet. Inter-sessional work should thus include:

- exploration of dominant mechanisms through which Baltic cod, sprat and herring recruitment, feeding, growth and maturation processes are influenced by fluctuations in the physical environment, both direct and indirect impacts
- estimation of variations in transportation of cod larvae into environments of different habitat suitabilities
- modelling of growth, sexual maturation and egg production of cod and sprat in relation to food consumption, food availability and environmental conditions in the framework of EU-project STORE
- develop, apply and validate some new models for multispecies predictions, which take into account as much as possible abiotic and biotic processes.

SGMPB should inter-sessionally start to explore the feasibility of introducing statistically based spatial multispecies frameworks (BORMICON-type model) in the Baltic, allowing modelling of migration rates in comparison to observations from tagging experiments.

Finally, SGMPB should also explore possibilities to implement more simple multispecies models especially in view of uncertainties in catch at age and weight at age data (inconsistencies in age determinations) observed in recent years. One possibility is to explore Schaefer type multispecies production models. The major advantage of these models are that they do not require to resolve the age structure of the population, which seem to appropriate especially in the case of Baltic cod, where we still have a serious problem in age determinations.

8 RECOMMENDATIONS

Multispecies working groups and various multispecies study groups in the past have composed a useful forum allowing scientists to develop multispecies models and prepare an up-to-date summary of multispecies issues.

As mentioned in Section 1, the SGMPB benefits from and is dependent very much on the activities outside ICES framework. The timing of these activities and results obtained will thus define very much the future activities of SGMPB.

SGMPB has requirements to complete some tasks each year. For example compiling the basic information into the database for Baltic fish stock assessment and perform necessary key runs used by WGBFAS. Therefore it is **recommended** that SGMPB work by correspondence in 2002.

SGMPB has been very fortunate to been able to use findings and results from various projects. These projects will complete their work later in 2001 and 2002 and thus it is **recommended** that next meeting of SGMPB will take place in 2003. Same time SGMPB considers that at the moment it is premature to propose terms of reference for its next meeting, because the terms of reference are heavily dependent on development and outcome of various projects outside ICES.

In ICES, the Baltic multispecies issues are tackled only by SGMPB. WGBFAS does not handle multispecies basics and it does not have expertise to update MSVPA and run multispecies predictions. Therefore there is need to arrange a 4M training workshop in 2002 and SGMPB is **recommending,** that ICES should take necessary actions to organize such a training course on multispecies modelling issues in the Baltic in connection to Baltic fish stock assessment activities. SGMPB is prepared to provide necessary expertise for such a training course. Further discussion about this should take place during the ASC 2001 in Oslo by the Baltic Committee.

The maintenance of the database, data-base revisions and update needs input from SGMPB and from the Danish Institute for Fisheries Research to keep 4M package operative.

For the future it is also necessary and SGMPB **recommends,** that 4M program package as well as necessary data-bases are installed on ICES systems. 4M is currently ready for such implementation.

The database for Baltic fish stock assessment for 1974 to present needs some correction work and the data-base should as far as possible be extended to the period prior to 1974. Therefore SGMPB **recommends,** that ICES should explore possibilities to set up an internationally co-ordinated project on compilation, validation and maintenance of basic assessment data for the Baltic stocks. The western Baltic MSVPA database and analysis has not been updated since 1998 and this is also one of the major tasks.

The main task of this kind of internationally co-ordinated project should be the following:

- validate the newly compiled basic catch at age and weight at age in the catch data-base according to quarter and sub-division for the period 1974–1992
- explore the possibilities to expand the data-base back in time to 1960s and early 1970s including stomach data
- set-up of a data-base on weight at age in the stock derived from historical and ongoing research survey activity
- outline strategies and procedures for annual updating and maintenance of the database
- a high priority should be allocated to solve the age-reading inconsistencies allowing to set-up a procedure correcting available age-based data sets.

The basis of constructing environmentally based short-term prediction and medium- to long-term projection models, it is important to review all available information on environmental processes affecting the population dynamics of Baltic herring. Therefore SGMPB **recommends,** that Baltic herring expertise must be incorporated into the SGMPB in order to structure and rank the relevance of major processes for predictions of Baltic herring stock components and to include important variables and parameters into multispecies predictions.

9 REFERENCES AND WORKING DOCUMENTS

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APPENDIX 1 – AREA DIS-AGGREGATED MSVPA RUN UPDATE

In the Baltic Sea the spatial and temporal suitability of the spawning habitats of cod (*Gadus morhua*) vary dramatically with the oxygen conditions at the depth of incubation of the eggs (e.g., Wieland *et al.* 1994). As a consequence, the population dynamics of cod exhibit distinct trends in different areas of the Central Baltic (Sparholt and Tomkiewicz 2000), with a corresponding variation in predation pressure on its major prey species, sprat (*Sprattus sprattus*) and herring (*Clupea harengus*) (Sparholt 1994). In turn the population development of these planktivores determines the predation intensity on early life stages of cod (Köster and Möllmann 2000). Hence in order to develop sustainable management strategies for the Central Baltic stocks, assessments and stock projections should resolve and incorporate the effects of environmental variability and species interactions on reproductive success, in particular the potential for different spawning localities to contribute to recruitment success. At present MSVPAs are run for two areas in the Baltic, a Western and Central Baltic component to match the stock units used in the regular stock assessments, with the Central Baltic component dominating in terms of biomass and abundance (ICES 1998/ACFM:16).

Within these two regions, the abundance and biological characteristics of the three species are heterogeneous both spatially (between Sub-divisions) and temporally (inter and intra annually). For example, population sizes of Central Baltic cod, as resolved by international bottom trawl (Sparholt and Tomkiewicz 2000) and ichthyoplankton surveys (Köster *et al.* this 2001), have revealed distinct distributional trends. Furthermore, for cod substantial differences in weight at age and maturity ogives have been reported for different Sub-divisions (ICES 1997/Assess:12, Tomkiewicz *et al.* 1997). The abundance and characteristics of herring and sprat have also been observed to vary spatially and temporally in the different Sub-divisions of the Central Baltic (e.g., Ojaveer 1989). The herring stock in the Central Baltic is comprised of a number of different spawning components exhibiting variations in spawning period and growth rates as well as meristic, morphometric and otolith characteristics (e.g., Parmanne *et al.* 1994). For sprat the existence of distinct populations is controversial as deviations in growth rates observed between sub-areas have been explained by immigration from the western Baltic and by migration between different basins (Parmanne *et al.* 1994). However, other authors state that sprat in the eastern Central Baltic form local populations (Ojaveer 1989), which can be separated, primarily by otolith characteristics (Aps *et al.* 1981).

MSVPA set-up

Stock structure

Cod, sprat and herring in Sub-division 25, 26 and 28 were assumed to be unit stocks. Age groups 0–9 were considered for cod and herring and 0–7 for sprat (oldest age-groups: no plus-groups).

Catch at age and weight at age

Quarterly catch at age in numbers and weight at age in the catch according to Sub-divisions were revised and updated for years 1974–1992 following the compilation scheme presented in ICES (1997/J:2). Corresponding input for 1993–1999 are based on data reported by the national laboratories to the Baltic Fisheries Assessment Working Group with following changes:

- Catch and weight at age of cod by the Danish fleet was separated from 1985 onwards to Sub-divisions according to logbook data, splitting also the catches in the former “white zone“ (assuming 25% to belong to Sub-division 26 and the remaining part to Sub-division 28).
- To avoid tuning problems in cases when catch at age data in the 4th quarter of the final year or for the oldest age-groups were absent, the annual catch was split into quarters according to the average seasonal distribution encountered in that age-group and area over the covered time period. This assumes, that catches were obtained in each quarter, but not reported.
- Cod weight at age-group 0 to 2 in the stock and in the stomach were reset to values used by ICES (1999/H:5), due to size selection of the commercial gears and the limited sample sizes being basis of the calculation of weight at age in the catch.

Maturity ogives

Maturity ogives for cod in different Sub-divisions represent averages over the periods 1980–84 (applied also before 1980), 1985–89, 1990–94 and 1995–97 for combined sexes as presented in ICES (1998/ACFM:16), updated with data for 1998 and 1999 presented in ICES (1999/H:5) and ICES (2000/ACFM:14). For sprat and herring maturity ogives were used as given in ICES (1996/Assess:2), being constant over time.

Stomach content data

Quarterly cod stomach content data according to Sub-division as revised in ICES (1997/J:2) were utilized as input. Intra-cohort cannibalism in cod was excluded by changing prey age to predator age minus 1 and omitting 0-group cod in 0-group cod stomachs.

Quarterly food intake by cod

Consumption rates estimated within the first reporting period according to quarter year and Sub-division were applied.

Tuning

The tuning of the MSVPAs was performed for each Sub-division utilizing the procedure developed by Vinther (2001), iteratively running MSVPAs and XSAs with automatic recursive data exchange. The XSA settings were as follows:

Cod:

- including age-groups 2–7 abundance indices from international bottom trawl surveys 1994–1999 compiled in Subtask 1.1 during the first reporting period,
- catchability was set to be dependent of stock size for ages < 3 and independent of age > 5,
- shrinkage of the terminal population towards a mean F over last 5 years and 3 oldest ages was applied with a standard error of 0.5–0.8,
- otherwise default settings of the Lowestoft assessment programme package were used.

Sprat:

- using international hydroacoustic survey results as tuning fleets; depending on the performance covering 1987 or 1992 to 1999 with year 1993 excluded, as insufficient area coverage and problems in the intercalibration of the equipment occurred (ICES 1997/Assess:12),
- catchability was set to be dependent of stock size for ages < 3 and independent of age > 4,
- shrinkage of the terminal population towards a mean F over last 3–5 years and 3–5 oldest ages was applied with a standard error of 0.5–0.8,
- otherwise default settings of the Lowestoft assessment programme package were used.

Herring:

- using international hydroacoustic survey results as tuning fleets; depending on the performance covering 1982 or 1986 to 1999 with 1992/1993 excluded in Sub-division 25, 1993 in Sub-division 26, 1993 and 1997 in Sub-division 28 as insufficient area coverage and problems in the intercalibration of the equipment occurred (ICES 1997/Assess:2; ICES 2000/ACFM:14),
- catchability was set to be dependent of stock size for ages < 3 and independent of age > 5,
- shrinkage of the terminal population towards a mean F over the last 5–6 years and 6–7 oldest ages was applied with a standard error of 0.8–1.0,
- otherwise default settings of the Lowestoft assessment programme package were used.

Residual natural mortality

The residual natural mortality was assumed to be 0.2 per year, equally distributed over quarters.

Other input data and setting

The constant biomass of other food was assumed to be 1 mill. tonnes, similar to ICES (1996/Assess:2).

Results

The derived spawning stock biomass values (SSB) for cod, herring and sprat in the different Sub-divisions determined by the final MSVPA runs are displayed in Figure 1. For cod a substantial decrease in the SSB is obvious in all three areas from 1983 onwards. After enhanced reproductive success and a reduction in fishing mortality in the early 1990s (see below) the SSB showed an intermediate increase in Sub-divisions 25 and 26. On the contrary, in Sub-division 28 no recovery was detected.

The SSB of sprat in Sub-divisions 25 and 26 showed a rather similar time trend (Figure 1), with a decrease from relatively high levels in the mid 1970s to very low SSB values in the beginning of the 1980s, followed by stable intermediate values in the second half of the decade. In the beginning of the 1990s a further substantial increase in the spawning stock is estimated for both areas, however, considerably more pronounced in Sub-division 25. Sprat SSB in Sub-division 28 was in general lower than in the other areas until the late 1980s, when the spawning stock level developed parallel to the component in Sub-division 26. In most recent years, a decline in SSB is obvious for all areas.

The herring SSB in Sub-divisions 25 and 26 showed a more or less continuous decline from the beginning of the time series (Figure 1). The decline is most pronounced in Sub-division 25 reaching similar spawning stock sizes as estimated for Sub-division 26 in most recent years. In contrast, the SSB in Sub-division 28 was rather stable throughout the 1970s and 1980s, showing a positive development in most recent years.

Recruitment of cod, herring and sprat at age 1 estimated for the different Sub-divisions are displayed in Figure 2. For cod an increasing trend throughout the second half of the 1970s and a decline from the early 1980s throughout the decade is obvious for all areas. The abundance of 1-group cod was estimated to be lowest in Sub-division 28 throughout the time series, with extremely low values calculated since 1990. In the second half of the time series, juvenile cod were computed to be most abundant in Sub-division 25.

Sprat recruitment values in the different Sub-divisions followed a similar time pattern since 1990 (Figure 2), with increasing intermediate recruitment in early 1990s, high recruitment of year-classes 1994, 1995 and 1998 and low recruitment of the year-classes 1993, 1996 and 1998, with the latter being, however, rather uncertain due to its direct dependence on terminal F-values for the last year. In years before, recruitment was variable, with outstanding year-classes 1973, 1975 and 1982, especially in Sub-division 26. Recruitment in Sub-division 26 was in general highest until the mid 1980s and lowest in Sub-division 28.

Time trends of herring recruitment at age 1 are in general rather similar in all sub-areass until the mid 1980s (Figure 1). Afterwards, recruitment in Sub-division 25 and 26 continued to decline, while herring recruitment in Sub-division 28 increased since 1988, being since the mid 1990s considerably higher than in both other areas.

A substantial difference in the cannibalism level of cod between the areas is apparent (Figure 3), with highest predation mortalities on 0-group cod from 1974–1982 in Sub-division 25. From then onwards 0-group cannibalism declined in all areas, being however always considerably higher in Sub-division 25, intermediate in Sub-division 26 and since the early 1990s very low in Sub-division 28. Also age-specific differences are pronounced, with predation mortalities on 0-group being considerably higher than on 1-group cod, with the exception of the early 1980s in Sub-division 26 and 28. Here high predation mortalities were estimated also for 1-group cod, while cannibalism in Sub-division 25 was considerably lower. Since 1987, predation mortalities on 1-group cod are rather similar in Sub-division 25 and 26, while corresponding values in Sub-division 28 decreased to very low levels. Predation mortalities of 2-group cod were in general low, i.e., less than the assumed residual mortality rates, with highest values estimated for Sub-division 28.

The determined predation mortalities of juvenile sprat showed a more or less continuous decline until mid of the 1980s (Figure 4), with M2-values of adults being more stable until 1983. Throughout the 1990s, predation mortalities were relatively low, i.e., in most years below 0.3. However, the predation pressure is different in the three Sub-divisions, being highest for 0-group in Sub-division 26 and for adult sprat in Sub-division 25, while values for Sub-division 28 were close to zero for all prey age-groups, which is related to the low predator population size in this area.

Predation mortalities of herring (Figure 5) were highest in Sub-division 26 in the beginning as well as at the end of the time series, independent of prey age. Similar to other areas, predation mortalities declined throughout the 1980s to lowest levels in 1991/1992, with a subsequent increase in most recent years, with the exception of Sub-division 28.

Fishing mortality rates of cod fluctuated in all Sub-divisions on a relatively high level from 0.4 to around 2.0 without any clear time trend (Figure 6). Highest fishing mortality rates occurred at low stock levels in the end of the 1980s and beginning of the 1990s, before restrictive fisheries management actions were enforced, resulting in relatively low fishing mortalities in 1993–1995.

The fishing mortality rates determined for sprat were highly variable in Sub-divisions 25 and 28, ranging from 0.05 to 0.9 (Figure 6). In Sub-division 26, catches and correspondingly F-values showed somewhat less variation. In all three areas, fishing mortality rates increased since 1993, caused by a developing industrial fishery, being most effective in Sub-division 25 and 26.

Increasing fishing mortalities of herring from late 1970s (ranging between 0.08–0.14 per year) until the mid 1980s (0.24–0.45 in maximum) were estimated for all areas (Figure 6). In Sub-division 25 and 26, the trend of increasing fishing pressure continued, while in Sub-division 28, pronounced fluctuations are encountered throughout the 1990s.

Comparison to abundance indices from international research surveys

Significant correlations between MSVPA estimates of cod population size (age-group 2+) and corresponding abundance indices utilised as tuning data are obvious for all three Sub-areas (Figures 7–9), with lowest r2-values in Sub-division 25 (r^2=0.28) and highest in Sub-division 28 (r^2=0.80). Large inter-annual variability encountered in the international bottom trawl survey in Sub-division 25 in 1982–1987 caused highest deviations between observed and modelled population abundance. Similarly in Sub-division 26, substantial deviations occurred in the beginning of the time series with an outstanding high trawl survey abundance index in 1982 and a relatively low one in 1983. On the contrary, the 1983 survey revealed highest abundance indices on record in Sub-division 28, which might indicate a shift in distribution compared to 1982 and subsequent years. Apart from this, indications of interannual shifts in distribution between different Sub-areas are not apparent.

For sprat the comparison between hydroacoustic survey results and MSVPA output revealed similar close correlations as obtained for cod (Figures 7–9), with lowest r2-values also in Sub-division 25 (r^2=0.62) and highest in 28 (r^2=0.86). The relatively low r^2-value in Sub-division 25 is mainly caused by an outlying high hydroacoustic population estimate in 1991 being a high positive residual also in Sub-division 26 and a negative one in Sub-division 28. In the latter area, also the 1992 survey estimate is an outlying low population estimate. According to ICES (1993/J:6), due to technical and area coverage problems, the hydroacoustic survey in 1992 is one of the most unreliable in the present time series, indicating rather a problem in the survey than in the MSVPA. Contrary to Sub-division 25, the increase in population size in Sub-division 28 in most recent years is more pronounced in the hydroacoustic survey than in the MSVPA.

In contrast to both other species, correlations between hydroacoustic survey derived abundance indices of herring in October and MSVPA output for the beginning of 4th quarter revealed no significant relationship in any of the Sub-divisions (Figures 7–9).

Comparison to area aggregated MSVPA results

The Central Baltic MSVPA covers the Eastern Baltic cod stock (Sub-divisions 25–32), the Central Baltic herring stock (Sub-divisions 25–29 + 32, including Gulf of Riga) and the Central Baltic sprat stock (Sub-divisions 25–32). These values can used for comparison with the output of the area disaggregated MSVPA runs integrated over Sub-divisions 25, 26 and 28. The assessment units for all three species are not directly comparable, as the area aggregated assessment comprises additionally at least Sub-division 27, 29 and 32. However, the major part of the cod catch (90–98%) is taken in the areas covered by the disaggregated MSVPAs (Sparholt and Tomkiewicz, 2000). For sprat areas covered in the present study sustain the major part of the sprat catch in the Baltic (around 80% in most recent years), nevertheless the disaggregated MSVPA based population size should to a certain degree underestimate the Central Baltic sprat stock.

Both estimates of cod SSB show a rather close development throughout time (Figure 10). The area-aggregated estimates are in general slightly higher, as to be expected from the incomplete area coverage by the disaggregated assessment. Exceptions are the most recent years, when the disaggregated assessment revealed slightly higher SSB values. Spawning stock estimates for sprat are as well following similar time trends (Figure 10). During the 1970s and especially the 1990s the disaggregated estimate is, however, considerably lower than the aggregated estimate. The order of the deviation in the beginning of the time series is to be expected from the difference in area coverage, but deviations in most recent years are most likely originating from the tuning process. For herring the trends in both SSB estimates are as well in line, with a steeper decline determined by the area disaggregated MSVPA in early years and a less pronounced decrease throughout the 1980s (Figure 10).

Cod recruitment estimates (age-group 2) were even better in agreement than spawning stock estimates, with a deviation in 1999, due to problems in tuning the youngest age-group within the last year of the assessment (Figure 11). Sprat recruitment determined by both assessments were following the same time pattern, however, the area disaggregated estimate being considerably lower in outlying high year-classes. For herring the absolute deviations between both assessments are larger than expected from the difference in area coverage.

Fishing mortalities for all three species are well in line between both assessments (Figure 12). Larger deviations were encountered in sprat at the beginning and the end of the time series, with the former indicating problems in tuning oldest ages-groups and the latter caused by deviations in tuning of the last years terminal-F values, explaining also above described differences in spawning stock biomass. Similarly, deviations in reference F were encountered for herring in most recent years, with the disaggregated estimate being, in contrast to sprat, lower than the aggregated.

Predation mortalities estimated for cod age-group 0, 1 and 2 (Figure 13) show only slight deviations between both assessments, which might be explained simply by the way averages have been calculated for the disaggregated runs, i.e., using plain arithmetic means, without weighting for differences in stock levels. This is in fact also true for the fishing mortalities presented above. Predation mortalities of sprat estimated by the area-disaggregated assessment were slightly higher in the beginning of the time series (Figure 14), and for adult sprat also throughout late 1980s and 1990s. These deviations can be explained by the fact, that predation pressure on sprat in Sub-division 29 and 32, incorporated into the area aggregated assessment, is extremely low due to the low abundance of the predator cod. A similar effect might explain the higher predation mortalities estimated by the disaggregated run for herring in all age-groups in all years covered (Figure 15).

Discussion

The performed area disaggregated MSVPA runs confirmed distinct trends in population abundance, spawning biomass, recruitment, predation mortalities and partly also fishing mortalities of cod, herring and sprat in different areas of the Central Baltic. As outlined in ICES (1999/H:5) a number of data related and methodological problems are involved in the present approach. The catch at age data for cod and sprat showed in some age-groups, quarters and years considerable fluctuations. High variability in the catch in numbers of the last age-group caused problems in tuning the terminal-F values for cod and sprat. For herring similar problems were not encountered. Beside catch at age and tuning problems, migration between different areas of the Central Baltic is expected to have an impact on the MSVPA results. Explicit inclusion of the migration process into the MSVPA-context is difficult and at present no adequate methodology is available (ICES 1999/H:5). Apart from this, reliable migration rates are missing for all stocks under consideration and databases required for an implementation of statistically based spatial multispecies models, e.g., BORMICON (ICES, 1995) are not readily available. Thus, presently the only feasible way of spatial disaggregation is to run a suite of independent MSVPAs for the different Sub-areas, as performed here. By doing this, migration is accounted for by fluctuations in the catch at age data only. A comparison of cod, sprat and herring spawning stock sizes and recruitment derived from area aggregated, disaggregated MSVPA and standard assessment runs revealed rather similar results in absolute estimates as well as time trends, considering still existing deviations in stock units. This confirms the finding described in ICES (1999/H:5): assessing the cod and sprat stock components separately does obviously not change the perception derived by the standard stock assessments for the entire Central Baltic, independent whether migration between different Sub-divisions occurs. A similar result was obtained by ICES (2001/ACFM:18) assessing herring in different biologically sensible stock units: i) Sub-division 25–27, ii) Sub-division 28, 29 and 32 and iii) the Gulf of Riga separately by XSA and than comparing the combined stock development to the standard assessment comprising Sub-division 25–29 and 32 inclusive the Gulf of Riga. The WG also made an attempt to compare short-term predictions conducted for the different stock units and the entire Central Baltic stock for stock specific F values corresponding to a yield to biomass ratio of 0.2. These predictions yielded a 16% higher catch in the area-disaggregated predictions for the following year, which was considered as a reasonably good agreement.

A comparison of direct stock abundance information from surveys to multispecies results revealed a good coherence in time trends for cod and sprat, but not for herring. For cod the relationships between both population estimates are highly significant in Sub-division 26 and 28, but in Sub-division 25 it explains only 28% of the variance. Furthermore a pronounced time trend in residuals was encountered with the MSVPA indicating substantially higher values than observed in the surveys and a vice versa situation in most recent years. Basically the survey revealed since 1993 abundance indices on the level encountered during early 1980s, with a decreasing trend up to 1992 only. A high spawning stock size in mid 1990s is suggested also by the egg production estimates derived by ichthyoplankton surveys conducted at peak spawning time (Köster *et al.* 2001), showing highest egg productions in the entire time period in 1994–1996. However, an increase in relative fecundity (Kraus *et al.* 2000) has contributed to the increase in egg production as well. In the eastern areas of the Central Baltic, the contrast in the data is considerably more pronounced than in Sub-division 25, explaining also the better correlation. Corresponding correlations between recruitment at age 1 derived by the international bottom trawl survey, being completely independent as not utilized for tuning, and the MSVPA revealed highly significant relationships for Sub-division 26 and 28, but not for 25 (Figures 16–18). This may be interpreted as evidence, that recruits originating from Sub-division 25 are growing up to a variable proportion in Sub-division 26, explaining also that in 13 out of 18 years recruitment indices were higher in the latter area, although the spawning stock was in general lower and environmental conditions for cod egg survival were worth (MacKenzie *et al.* 2000). For a more comprehensive evaluation of the output of an earlier area disaggregated MSVPA output, see ICES (1999/H:5).

For sprat the contribution of Sub-division 25 to the combined stock in the Central Baltic was found to be considerably higher in the MSVPA output than in the October hydroacoustic surveys, i.e., the absolute abundance estimates deviate by a factor of 4. In contrast, the absolute estimate for Sub-division 28 is substantially higher in the hydroacoustic surveys by nearly a factor of 3. Hydroacoustic surveys in May/June (ICES 1999/H:5) showed highest sprat concentrations in the Bornholm Basin as well, thus confirming the distribution pattern obtained by the MSVPA runs in principal, however significantly less pronounced. This may indicate a different distribution of sprat during spawning and feeding periods, potentially caused by migrations between area. A potential re-distribution of the sprat spawning stock during feeding time will have an effect on the SSB and recruitment estimated by the MSVPA runs for the different Sub-divisions. However, the major part of the catch is obtained during the 1st half of the year in a fishery directed to pre- and spawning concentrations, explaining why the relative distributions derived by the MSVPA runs and hydroacoustic surveys at spawning time are better in line.

Comparing recruitment estimates of age-group 0 determined by area disaggregated MSVPA runs and hydroacoustic surveys revealed significant relationships in Sub-division 25 and 28, but not in Sub-division 26 (Figures 16–18). Here an extremely high recruitment in 1982 as determined by the MSVPA runs was not reflected in the hydroacoustic surveys. Excluding this year-class resulted also in this area in a significant relationship. In all Sub-divisions, a considerable variability was encountered and the linear relationship explained 25–60% of the variance, which may first of all be explained by the high variability of age-group 0 in the hydroacoustic surveys. A drift of pelagic juvenile stages from Sub-division 25 to 26, similar to cod, may additionally impact on the recruitment estimates. However, as sprat spawn during the calmest period of the year the impact may be limited. Corresponding correlations for age-group 1 were highly significant, explaining 58–91% of the variance, but these estimates are not completely independent as age-group 1 hydroacoustic estimates were used in the tuning process.

In contrast to cod and sprat hydroacoustic survey estimates were not correlated to MSVPA results in herring, independent of the area considered. While the MSVPA runs showed declining abundances in Sub-division 25 and 26, herring population sizes in Sub-division 28 increased. The hydroacoustic surveys revealed rather variable population sizes with an increasing tendency until early 1990s, at least in the eastern Sub-areas, while throughout the 1990s a decline is indicated for all areas. While the deviations in early time periods are difficult to explain, the opposite trend in Sub-division 28 in most recent years is caused by an increasing population size of the Gulf of Riga herring (ICES, 2000) included in the MSVPA, but not in the hydroacoustic survey. Also in general, the difficulties encountered to validate the herring stock developments are caused by the heterogeneity of the stock structure as well as problems to assess the different components by research surveys utilized for tuning of the age-structured population model. Also the present approach of separation into Sub-divisions does not solve this problem, as different stocks inhabit same areas, and the borders of Sub-divisions are not equivalent with borders of stock distributions.

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Figure 1. Time-series of spawning stock biomass (SSB, 1st quarter) of cod, sprat and herring in the different Sub-divisions (SD) derived from area-disaggregated MSVPA.

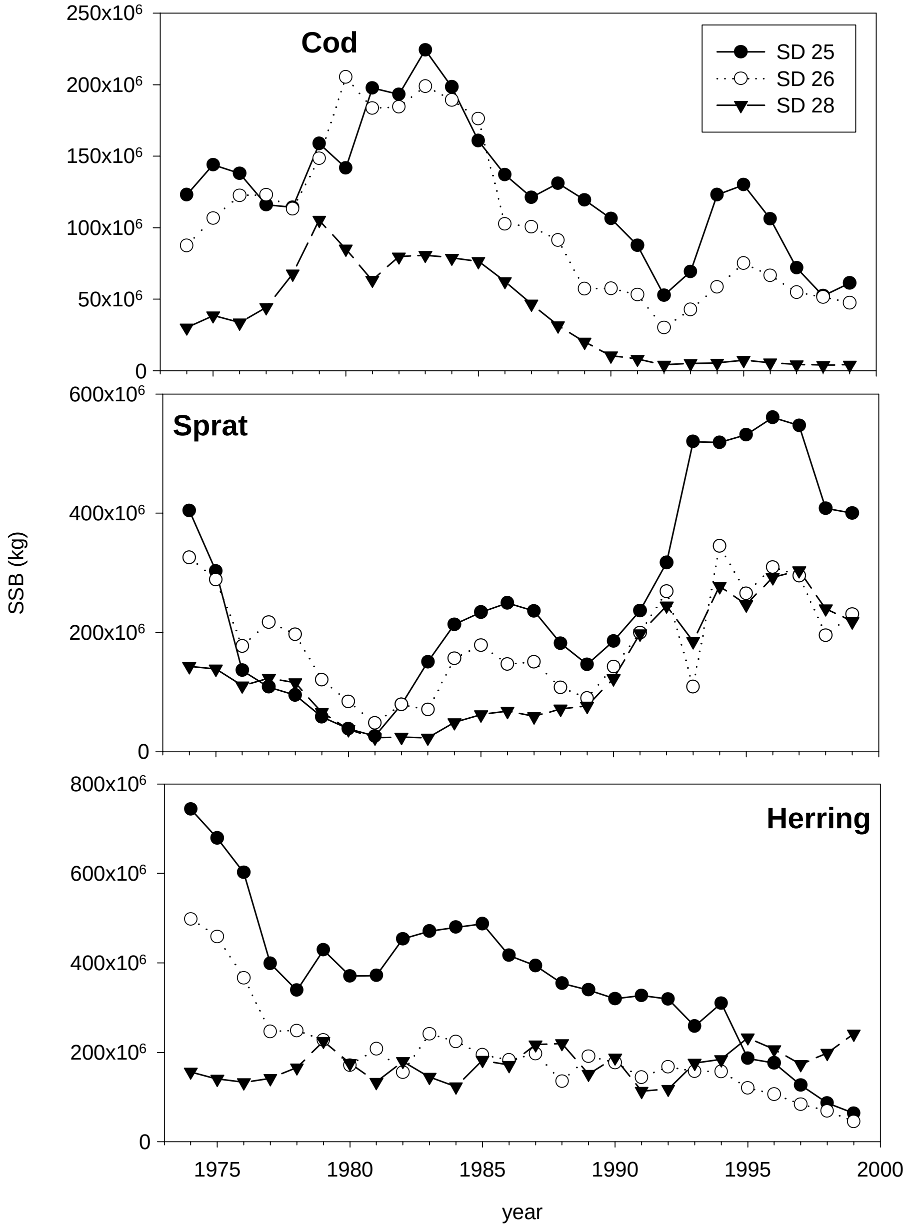


Figure 2. Time-series of recruitment estimates (1st quarter) of cod, sprat and herring in the different Sub-divisions (SD) derived from area-disaggregated MSVPA

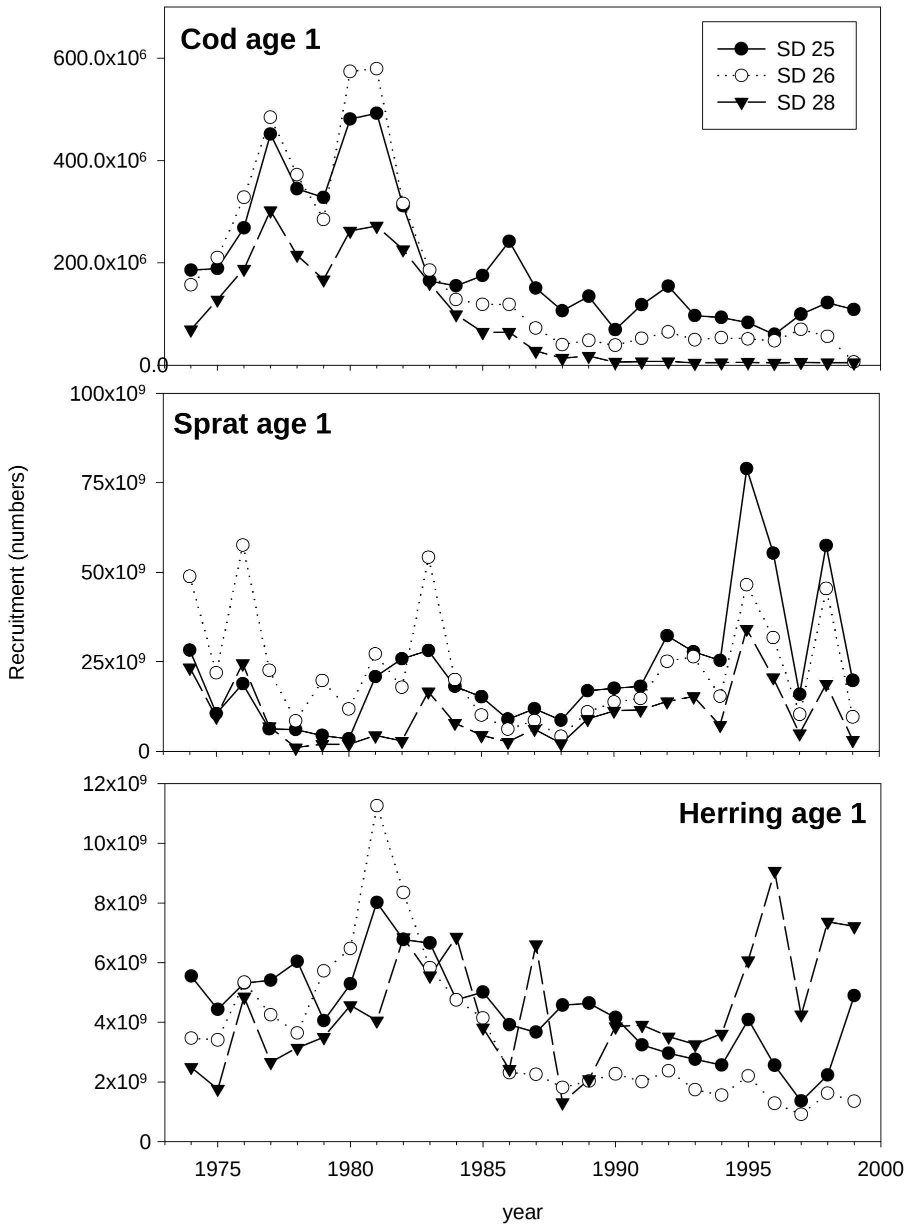


Figure 3. Time-series of annual predation mortalities of cod in the different Sub-divisions (SD) derived from area-disaggregated MSVPA.

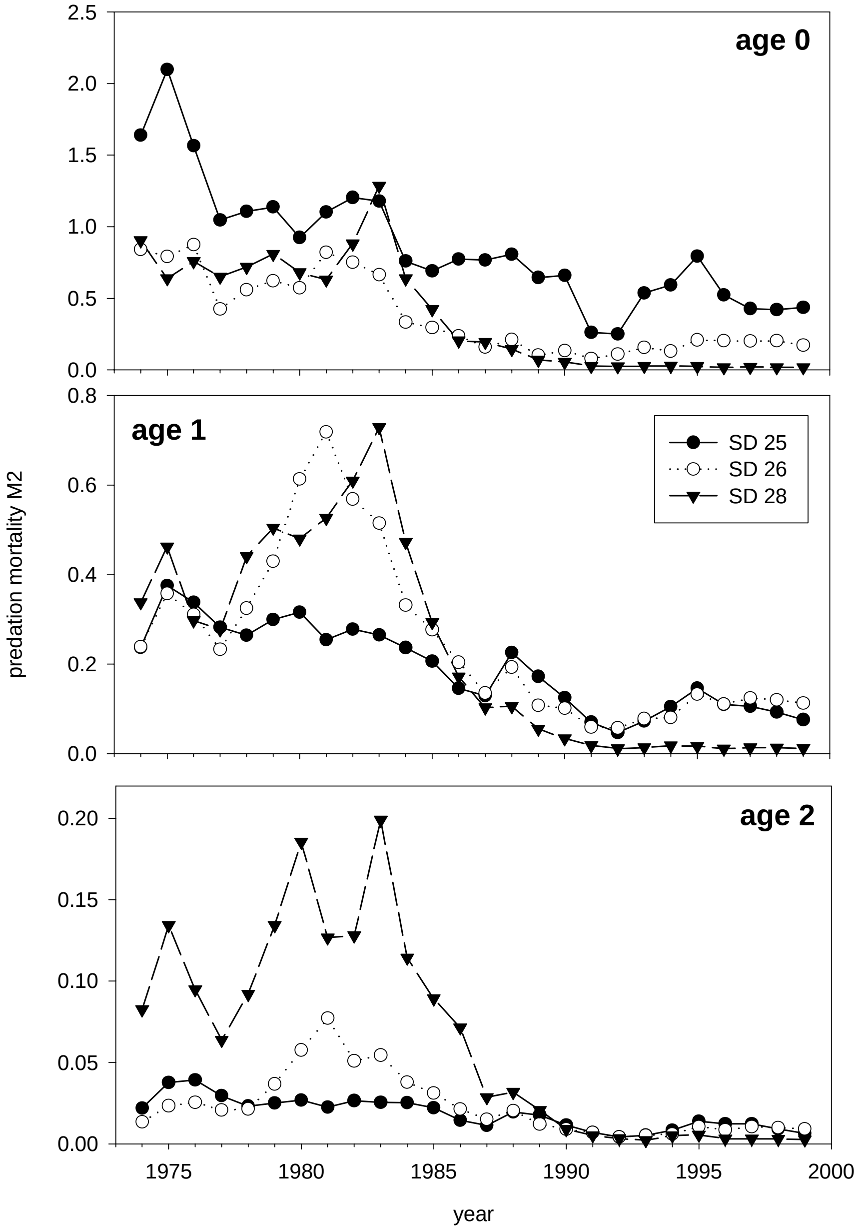


Figure 4. Time-series of annual predation mortalities of sprat in the different Sub-divisions (SD) derived from area-disaggregated MSVPA.

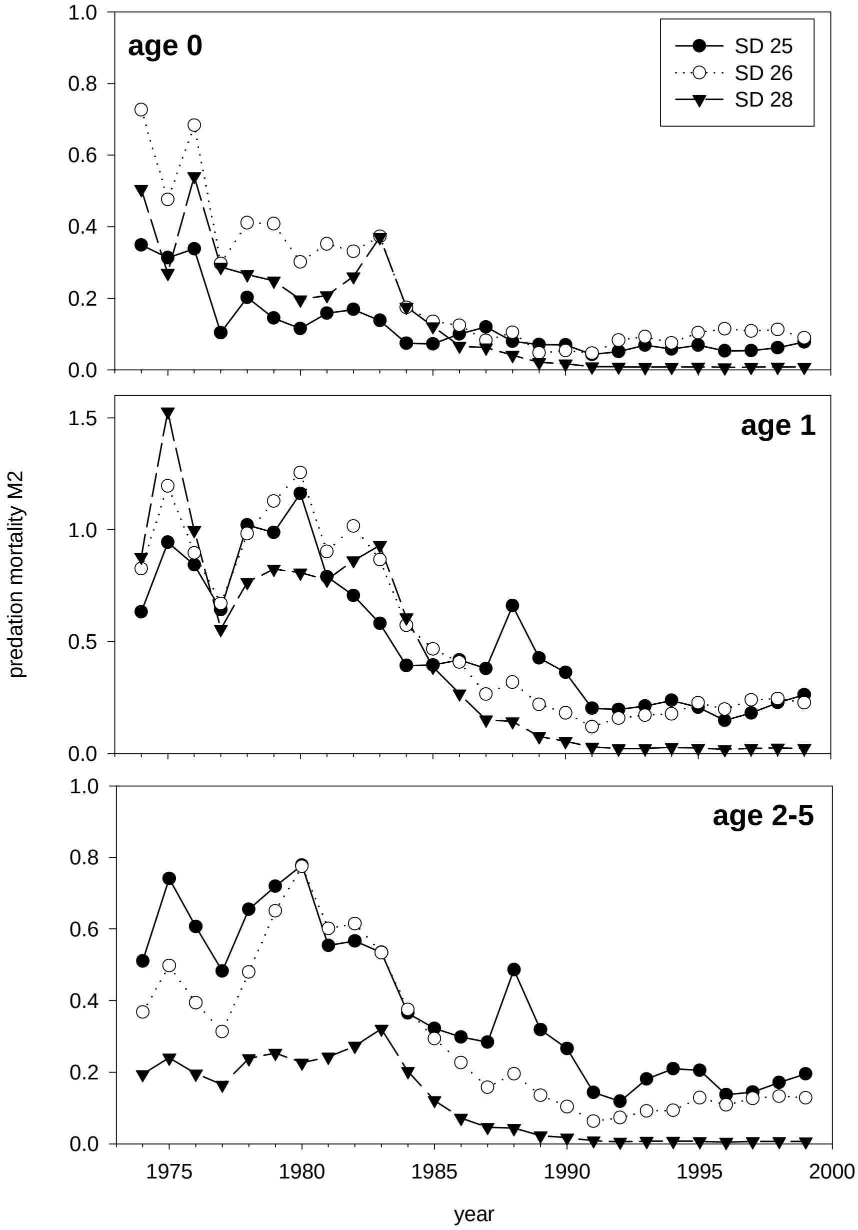


Figure 5. Time-series of annual predation mortalities of herring in the different Sub-divisions (SD) derived from area-disaggregated MSVPA

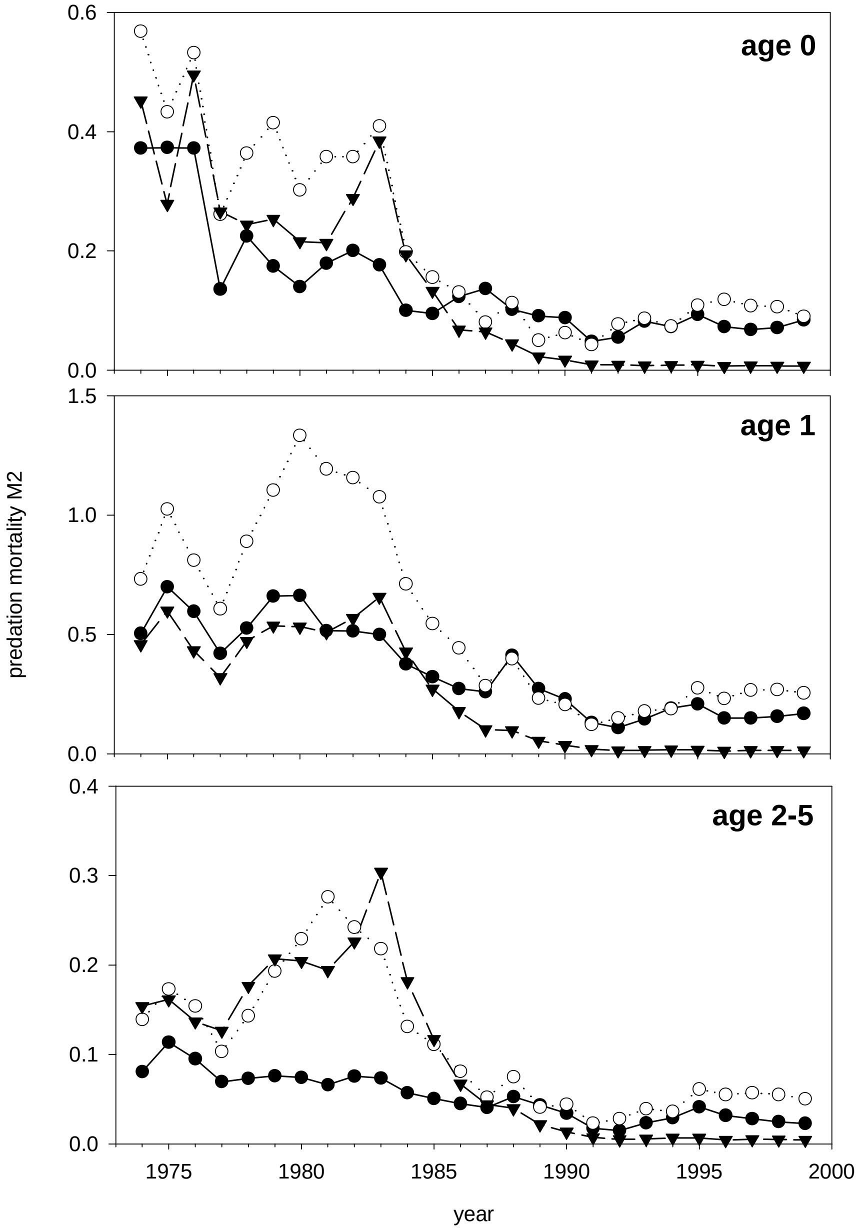


Figure 6. Time-series of annual fishing mortalities of cod, sprat and herring in the different Sub-divisions (SD) derived from area-disaggregated MSVPA.

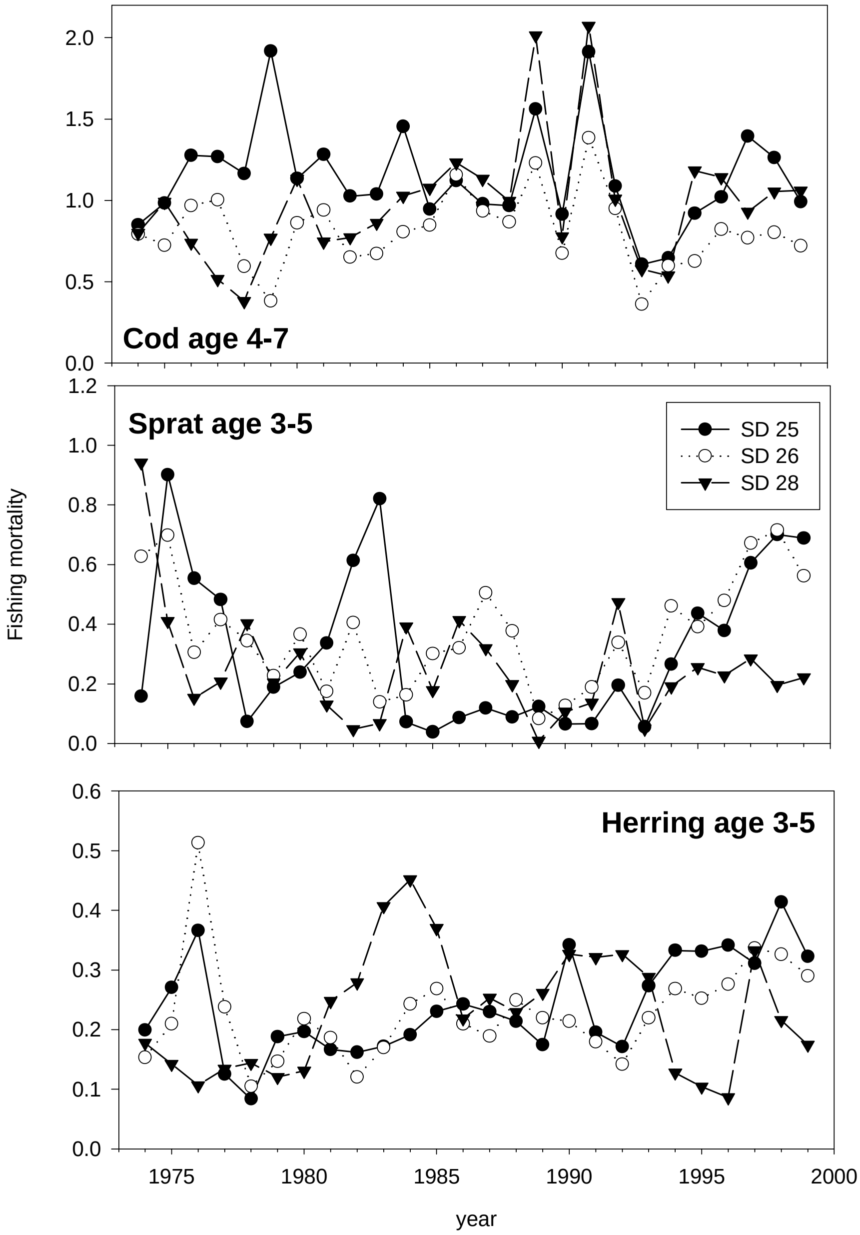


Figure 7. Comparisons of stock sizes (1st quarter) in Sub-division 25 from area-disaggregated MSVPA for cod, herring and sprat with survey data used for tuning (cod: Baltic International Trawl Survey, BITS; herring and sprat: International Hydroacoustic Survey). Left panels: Correlations; right panels: time-series.

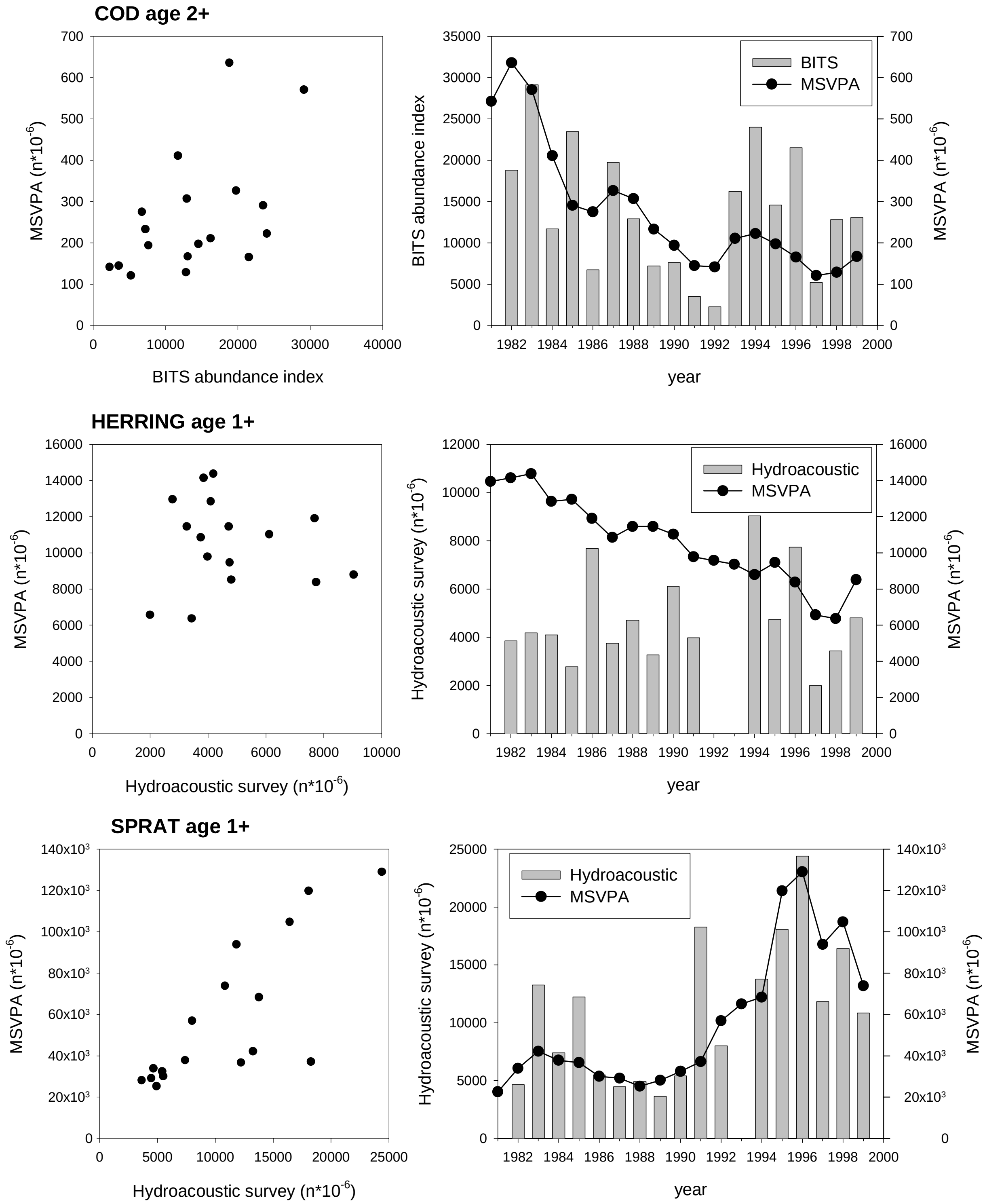


Figure 8. Comparisons of stock sizes (1st quarter) in Sub-division 26 from area-disaggregated MSVPA for cod, herring and sprat with survey data used for tuning (cod: Baltic International Trawl Survey, BITS; herring and sprat: International Hydroacoustic Survey). Left panels: Correlations; right panels: time-series.

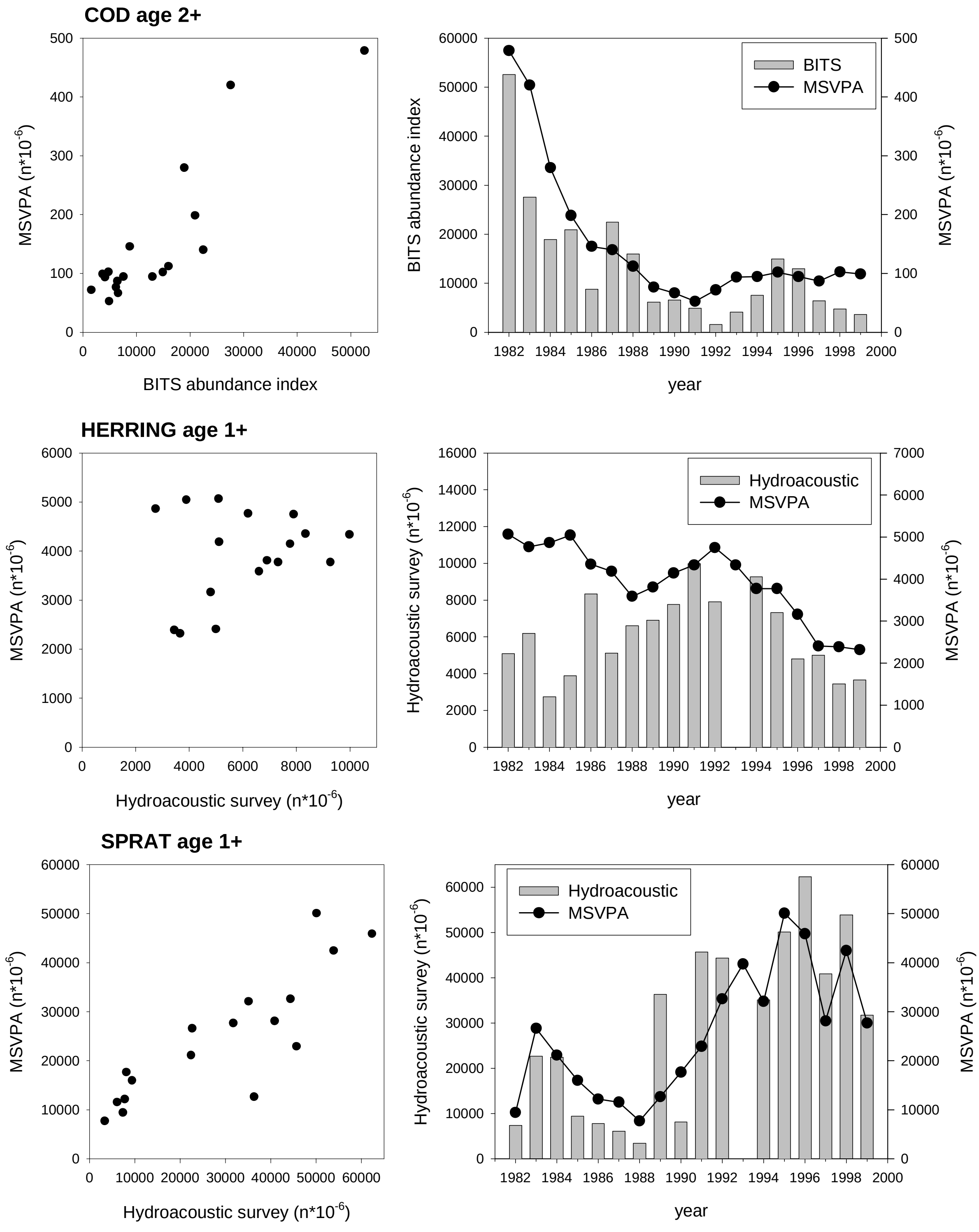


Figure 9. Comparisons of stock sizes (1st quarter) in Sub-division 28 from area-disaggregated MSVPA for cod, herring and sprat with survey data used for tuning (cod: Baltic International Trawl Survey, BITS; herring and sprat: International Hydroacoustic Survey). Left panels: Correlations; right panels: time-series.

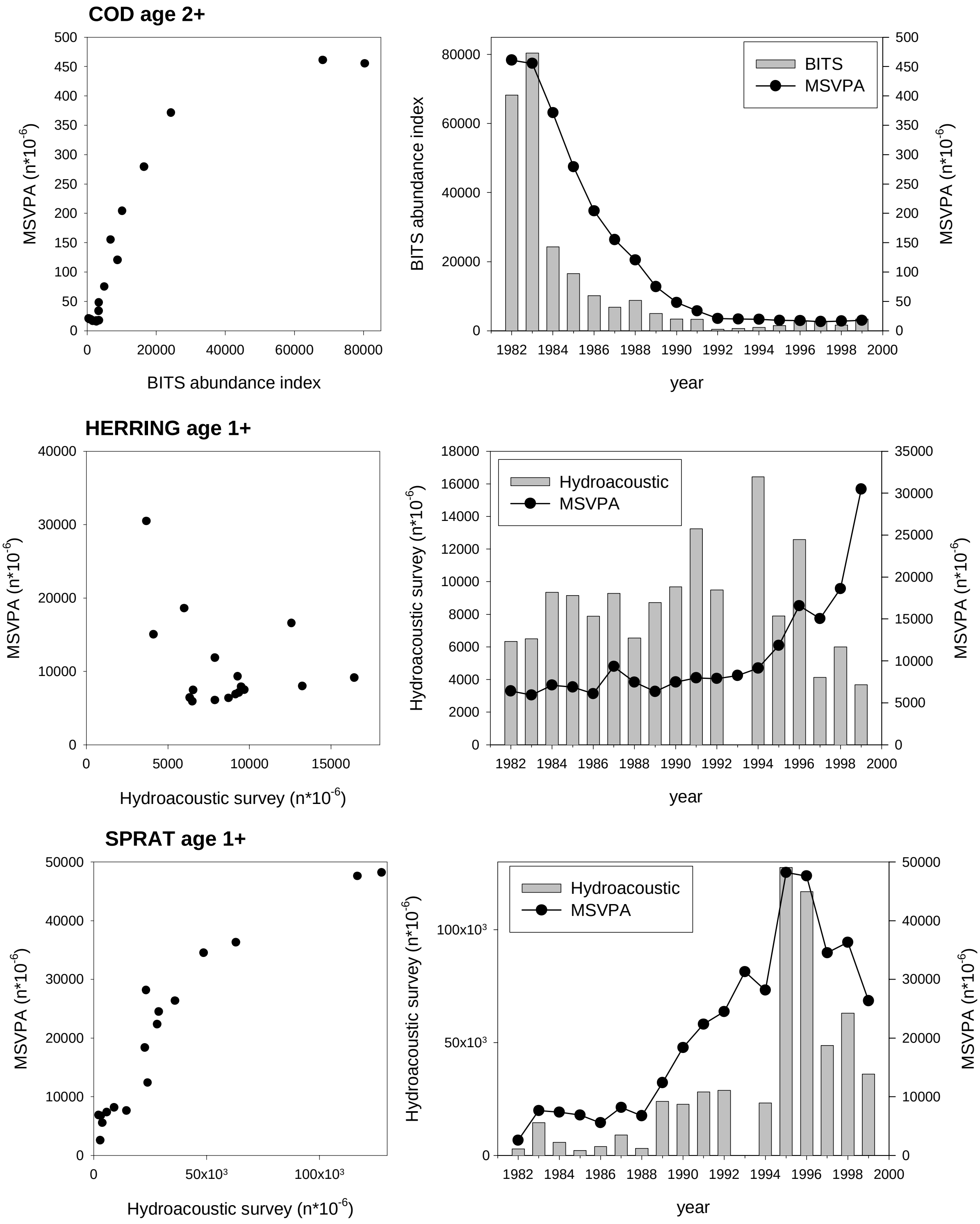


Figure 10. Time-series of spawning stock biomass (SSB, 1st quarter) of cod, sprat and herring derived from area-aggregated and area-disaggregated MSVPA.

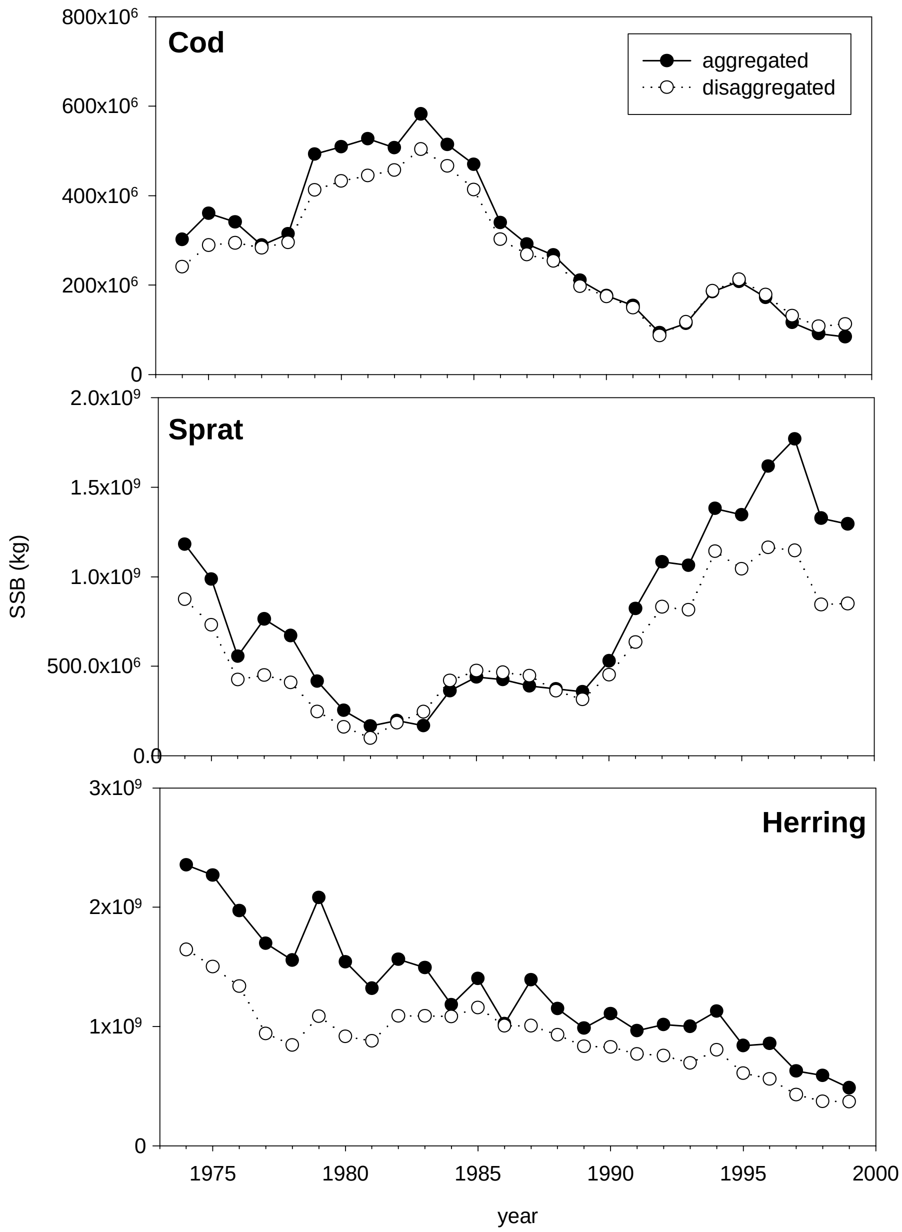


Figure 11. Time-series of recruitment estimates (1st quarter) of cod, sprat and herring derived from area-aggregated and area-disaggregated MSVPA.

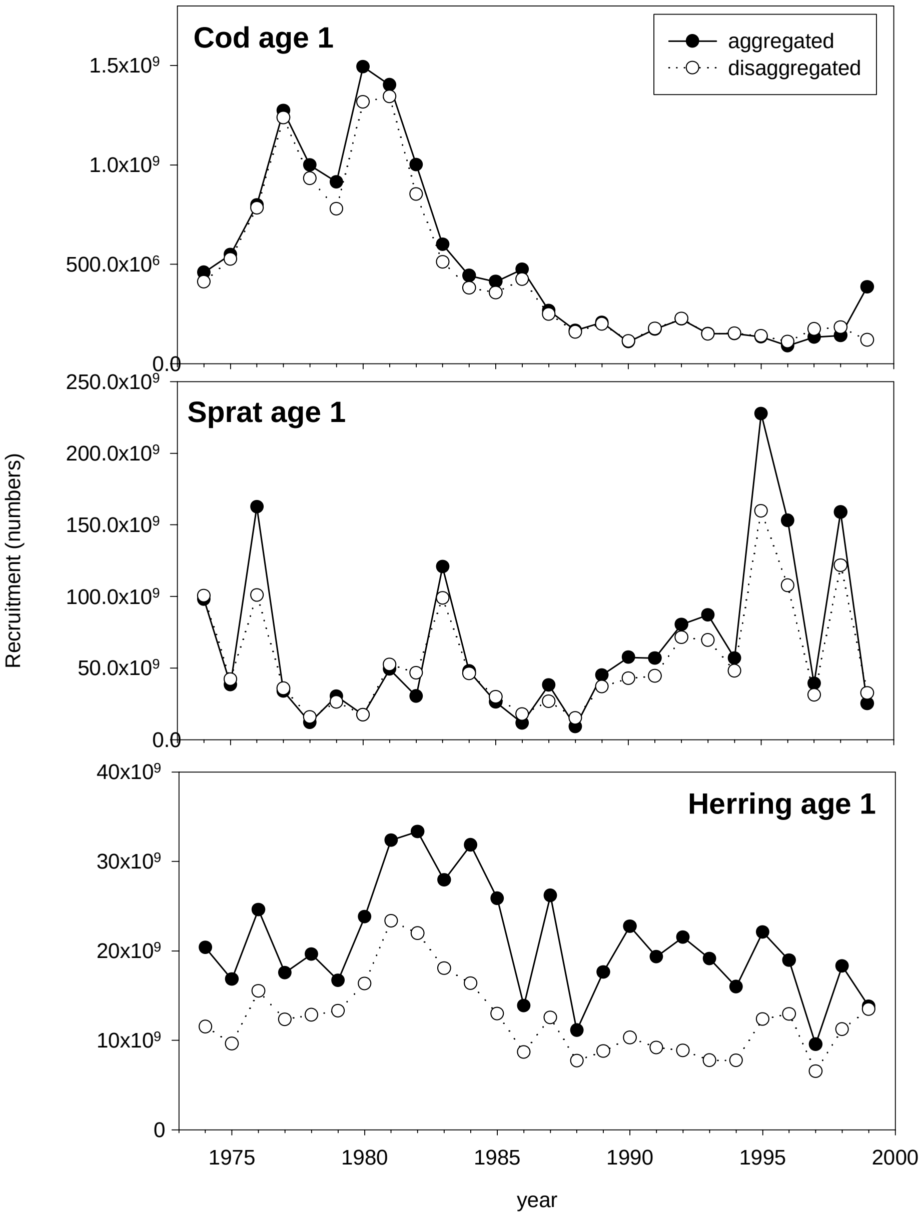


Figure 12. Time-series of annual fishing mortalities of cod, sprat and herring derived from area-aggregated and area-disaggregated MSVPA.

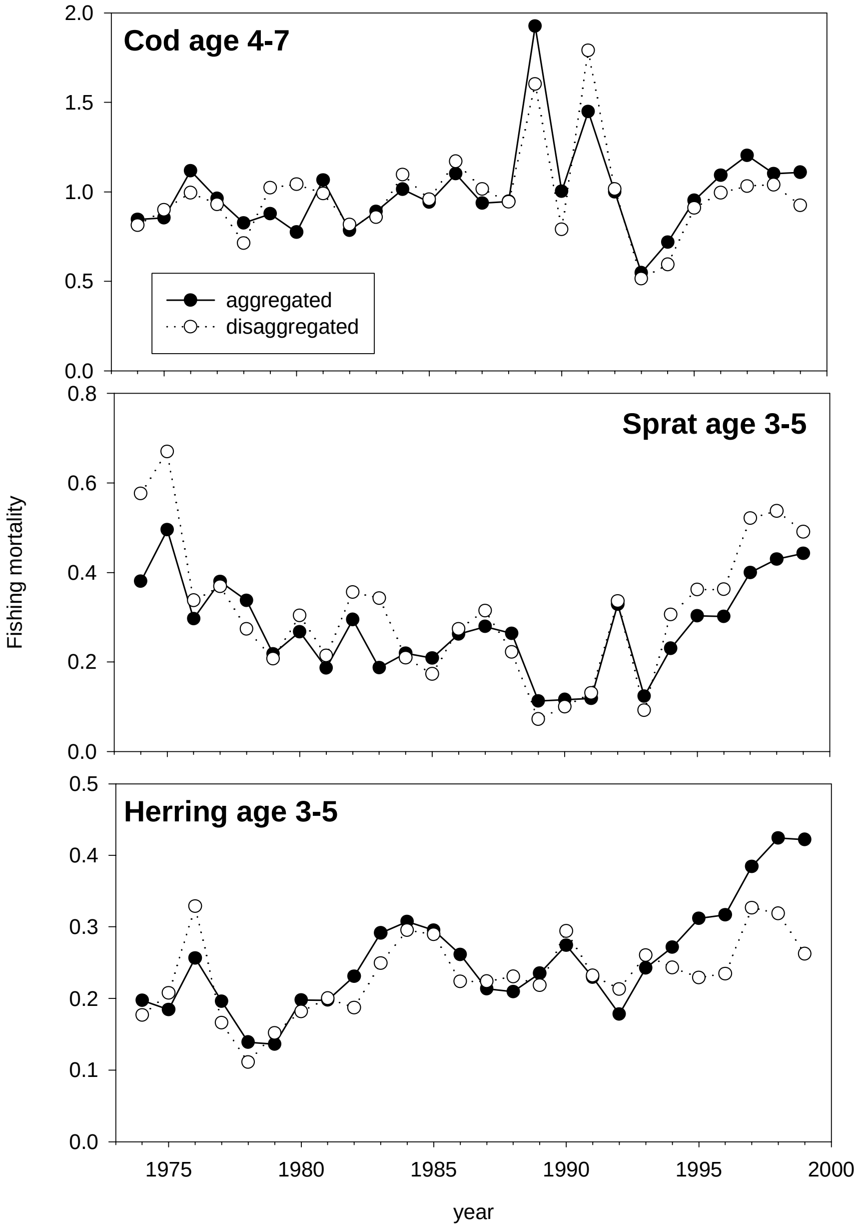


Figure 13. Time-series of annual predation mortalities of cod derived from area-aggregated and area-disaggregated MSVPA.

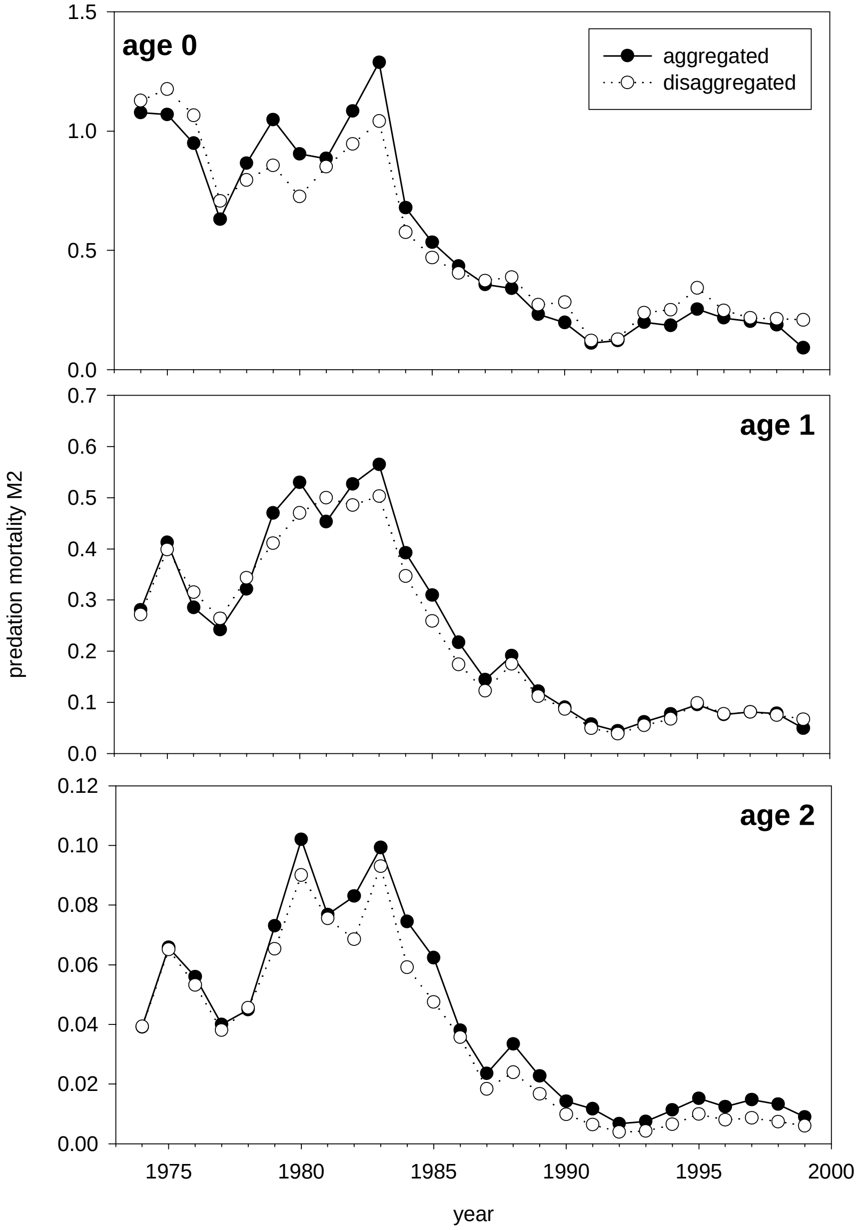


Figure 14. Time-series of annual predation mortalities of sprat derived from area-aggregated and area-disaggregated MSVPA.

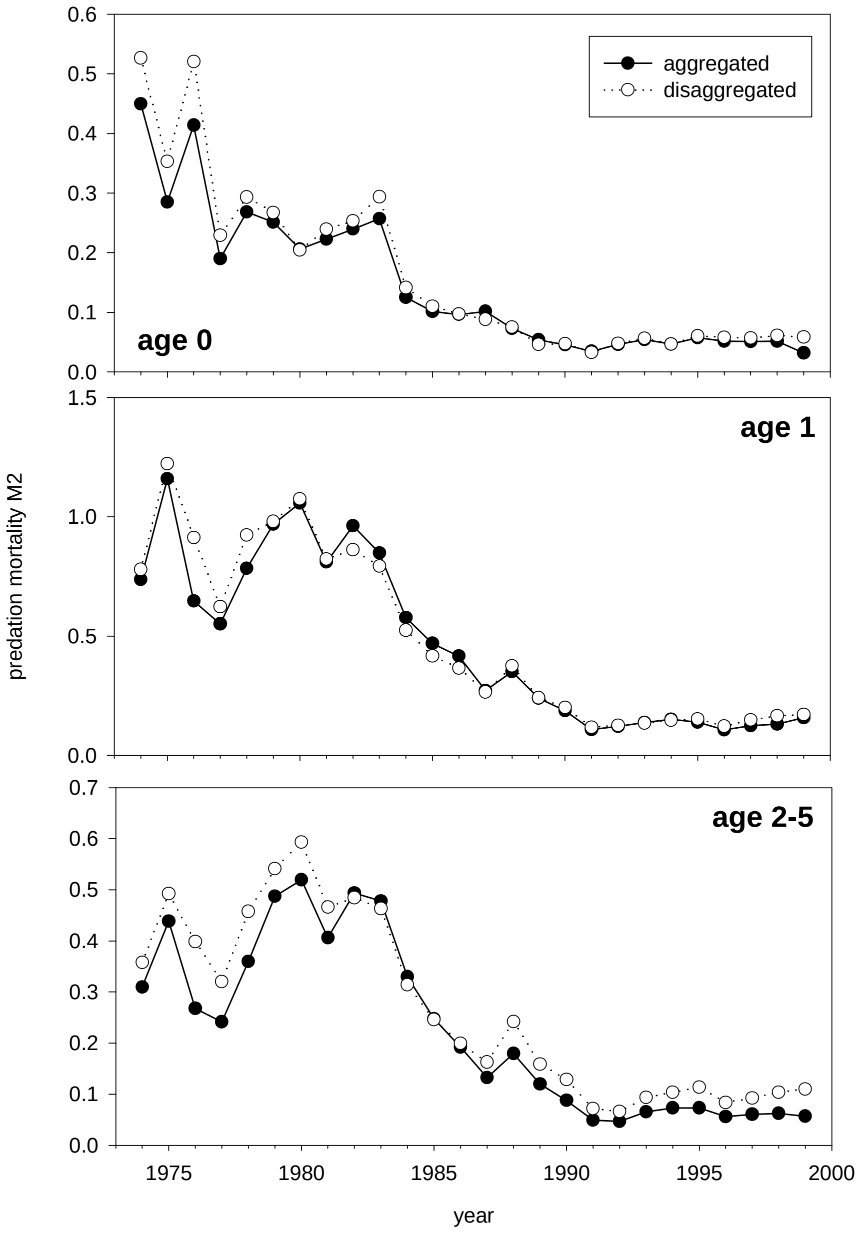


Figure 15. Time-series of annual predation mortalities of herring derived from area-aggregated and area-disaggregated MSVPA.

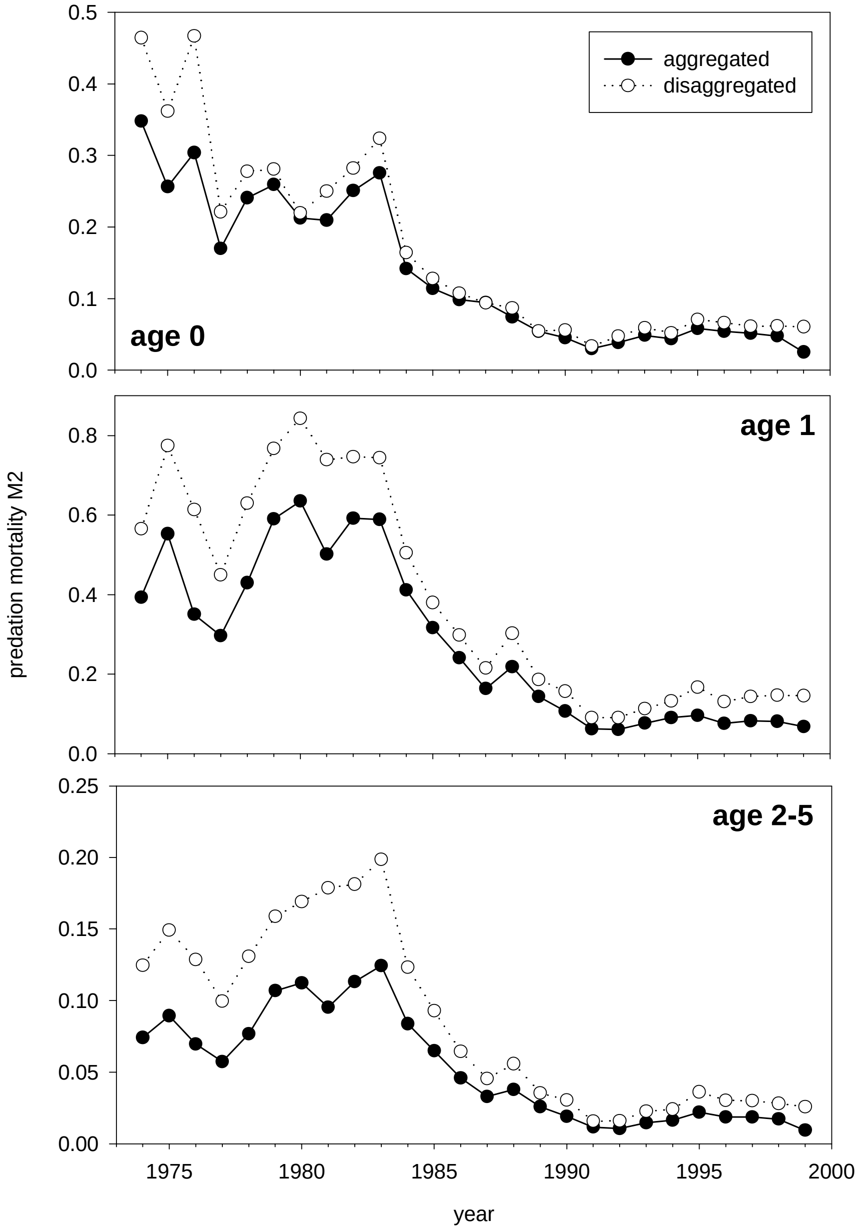


Figure 16. Comparisons of recruitment estimates (1st quarter) in Sub-division 25 from area-disaggregated MSVPA for cod and sprat with survey data used for tuning (cod: Baltic International Trawl Survey, BITS; sprat: International Hydroacoustic Survey). Left panels: Correlations; right panels: time-series.

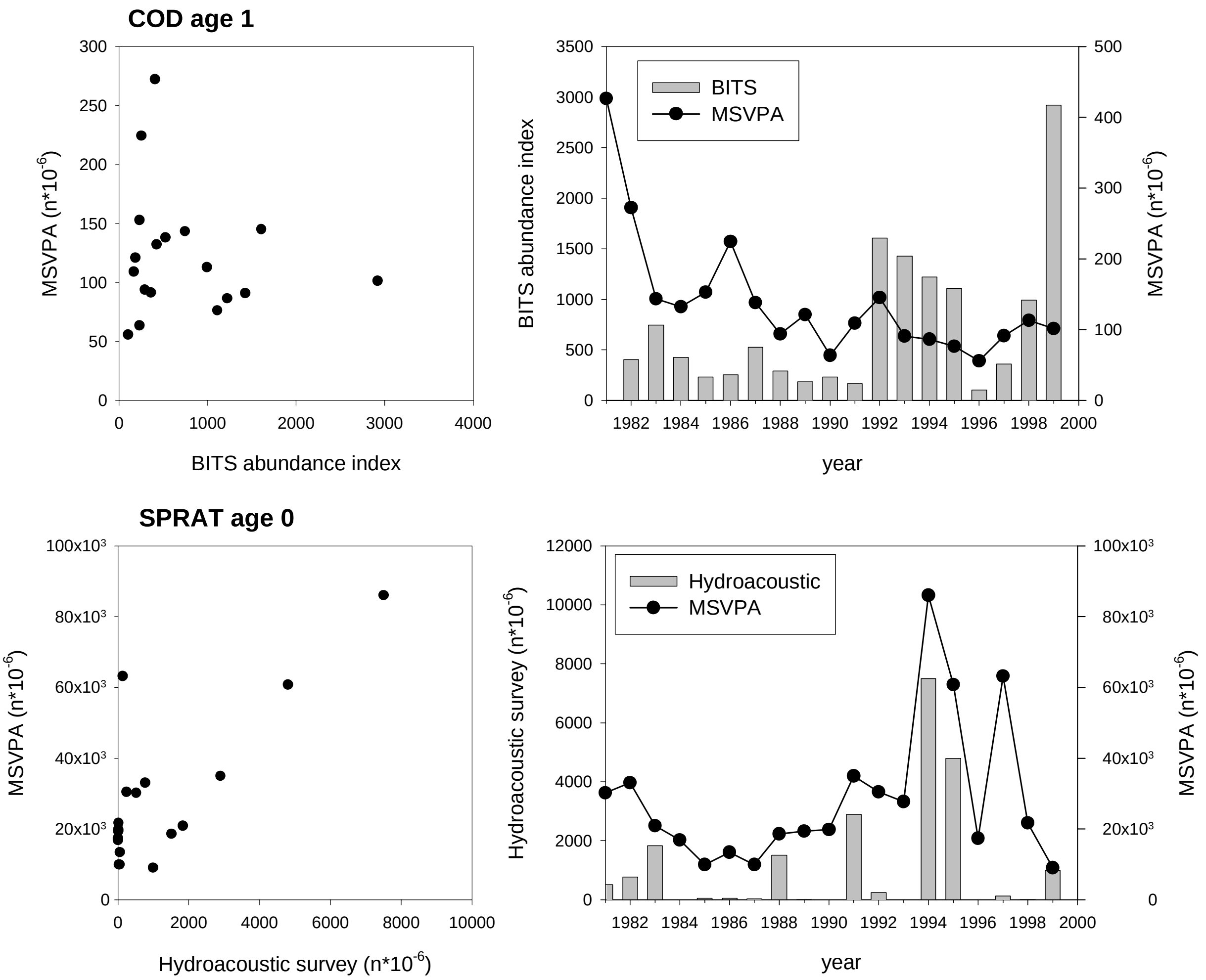


Figure 17. Comparisons of recruitment estimates (1st quarter) in Sub-division 26 from area-disaggregated MSVPA for cod and sprat with survey data used for tuning (cod: Baltic International Trawl Survey, BITS; sprat: International Hydroacoustic Survey). Left panels: Correlations; right panels: time-series.

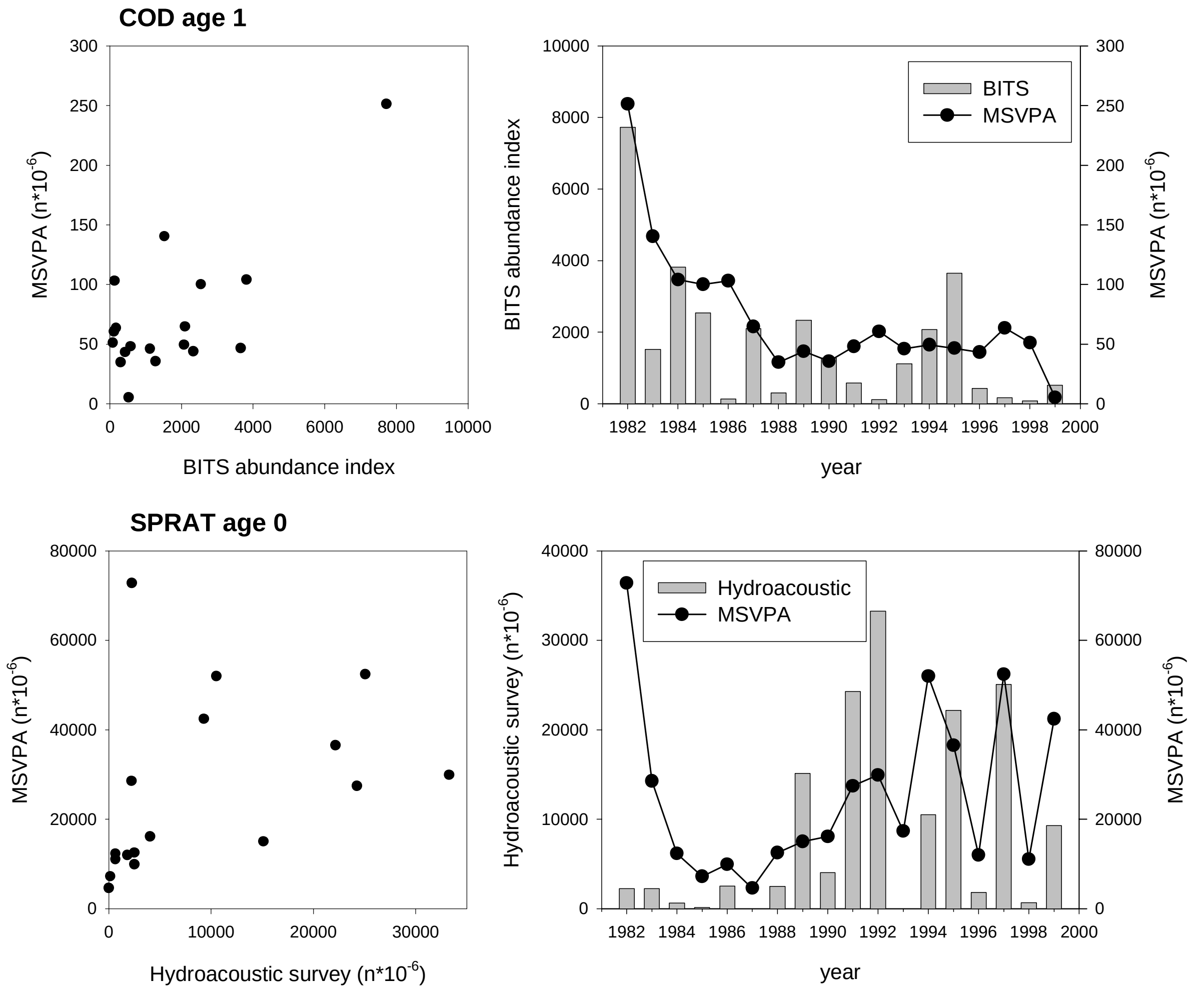
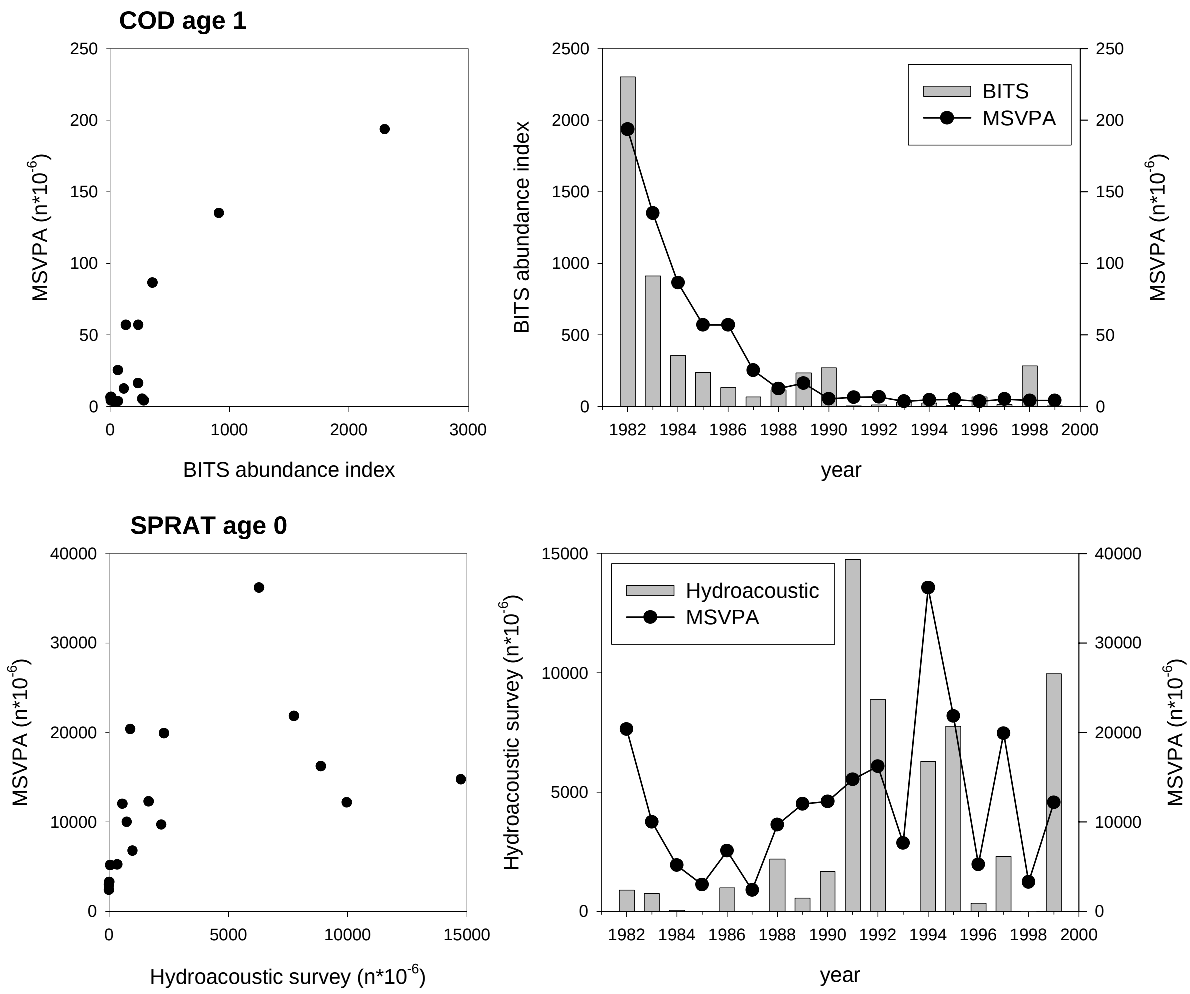


Figure 18. Comparisons of recruitment estimates (1st quarter) in Sub-division 28 from area-disaggregated MSVPA for cod and sprat with survey data used for tuning (cod: Baltic International Trawl Survey, BITS; sprat: International Hydroacoustic Survey). Left panels: Correlations; right panels: time-series.



APPENDIX 2 – LIST OF PARTICIPANTS

for

The Study Group on Multispecies Predictions in the Baltic [SGMPB]

Charlottenlund, Denmark, 7–11 May 2001

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